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DEVELOPMENT OF A STANDARD INTERFACE CONCEPT FOR SECURING WHEELCHAIRS IN ACCESSIBLE VEHICLES

Prepared for the
TRANSPORTATION DEVELOPMENT CENTRE
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TRANSPORT CANADA
January 1989

By
T E S Limited
Ottawa, Canada

With
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By

L.A. Garland, S.L. Dorion, H.E. Vietinghoff

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The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

Un sommaire en français de ce rapport est inclus avant la Table des matières.

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The continuing evolution of wheelchair design, which has resulted in a wide variety of sizes and shapes of wheelchair, has created a problem for accessible transportation systems.

Currently, no standardized method exists for securing wheelchairs in accessible vehicles; thus, in many cases the securement system available is not compatible with the wheelchair being transported, and system accessibility is adversely affected.

This report describes the development and evaluation of a concept for a standard interface to be used to allow wheelchairs to be secured in accessible vehicles. The report details the technical feasibility, the physical and performance requirements, an ergonomic evaluation and an economic impact evaluation of the standard interface.

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16. Résumé

L'architecture des fauteuils roulants, en pleine évolution quant aux formes et aux tailles observées, n'a pas été sans créer un problème aux exploitants de véhicules de transport adaptés: celui de l'ancrage à bord.

A l'heure actuelle, il n'existe pas de dispositif universel pour l'ancrage des fauteuils roulants à bord des véhicules. Souvent, celui qui se trouve à bord des véhicules ne correspond pas aux fauteuils à transporter.

Ce rapport décrit l'élaboration et l'évaulation d'un concept de dispositif universel, dont il donne les caractéristiques requises du point de vue technique, physique, ergonomique, économique et opérationnel.

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SUMMARY

This report describes the development of a standard interface concept for securing wheelchairs in accessible vehicles. This project was undertaken as a result of previous studies sponsored by the Transportation Development Centre (TDC) which concluded that a long-term solution to the problems associated with incompatible wheelchair/securement systems would involve some form of standard interface between the wheelchair and the vehicle. Such a standard system would be of great benefit in terms of convenience and operational safety to vehicle operators who have to cope with an increasing variety of wheelchair models.

Comments regarding the concept of a standardized interface were solicited from interested parties such as the Coalition of Provincial Organizations of the Handicapped, the Canadian Paraplegic Association, the Office for Disabled Persons of Ontario and Veterans Affairs Canada. Further, organizations addressing the non-compatibility situation in the wheelchair/securement/ restraint industry in terms of standards development and testing programs were contacted. These included the Ministry of Transportation of Ontario, wheelchair manufacturers and the International Standards Organization.

Design criteria for the standard interface were established to define the physical performance and ergonomic requirements. The foremost performance requirement, as identified at the project initiation meeting, was that a securement system, and thus the interface, must withstand a 20 g (g = acceleration due to gravity) load in a frontal collision. This is the level that vehicle components, such as seats and seatbelts, must withstand as stipulated in federal motor vehicle safety standards.

Several design concepts were developed based on the design criteria previously established. The concepts were not limited to the interface but were expanded to encompass entire securement systems. This was necessary in order that the technical feasibility of the standard interface concepts could be determined. A securement system was finally selected and subsequently approved by TDC for fabrication. This system consisted of sets of opposing hooks which rise out of the floor, secure onto mating pins fixed on the underside of the wheelchair, and pull downwards to secure the wheelchair. Several models were fabricated and then demonstrated for a range of wheelchair types. As well, a preliminary specification for the standard interface was developed.

An ergonomic assessment and an economic impact analysis of the general concept of a standard interface were performed. The ergonomic evaluation revealed that issues such as wheelchair alignment, operational methods and weight of any add-on to the wheelchair were important considerations. The economic impact analysis revealed that implementation of a standard interface system is not excessively costly and in fact may even improve paratransit operating efficiencies to the point where a reasonable payback is possible.

This project demonstrated that the concept of a standard interface for wheelchair/vehicle securement systems is technically feasible. The best long-term solution to the problem, however, is to develop a standard for transportable wheelchairs which would include a definition of the standard securement interface with which it must be equipped.

SOMMAIRE

Ce rapport décrit le processus de conception d'un dispositif universel pour l'ancrage des fauteuils roulants dans les véhicules de transports adaptés. Cette tâche découle d'études antérieures parrainées par le Centre de développement des transports (CDT) et qui avaient montré que, à long terme, la solution au problème de l'ancrage des fauteuils roulants dans les véhicules adaptés consisterait à trouver un dispositif universel ayant l'avantage d'allier commodité et sécurité, qualité à laquelle les exploitants seraient particulièrement sensibles, vu le nombre croissant de modèles sur le marché.

Afin d'obtenir des opinions éclairées sur la question, des organismes comme la Coalition des organisations provinciales pour les handicapés, des associations comme l'Association canadienne des paraplégiques, le Bureau pour les handicapés de l'Ontario et Anciens combattants Canada ont été approchés. D'autres intervenants préoccupés par la nécessité d'adopter des critères uniformes de conception, de réalisation et de mise à l'épreuve des dispositifs d'ancrage et d'immobilisation, comme le ministère des Transports de l'Ontario, les fabricants de fauteuils roulants et l'Organisation internationale de normalisation (ISO), ont également été contactés.

Des critères de conception ont été adoptés à cet égard. Ils permettent de définir les spécifications physiques et ergonomiques auxquelles le dispositif doit satisfaire; notamment, comme il avait été établi au cours de la réunion définition du projet, la nécessité de résister à des accélérations de 20 g (g étant l'accélération due à la pesanteur) en cas de collision frontale. C'est d'ailleurs l'exigence stipulée dans les normes fédérales sur la sécurité des véhicules automobiles et applicables particulièrement aux sièges et aux ceintures de sécurité.

Les chercheurs ont imaginé divers concepts fondés sur ces critères; ils ne se sont pas limités au seul aspect de l'ancrage, s'étant également intéressés à l'ensemble de la question de l'immobilisation des passagers. Cette étape était nécessaire afin de pouvoir déterminer la faisabilité technique de chacun des concepts proposés. Un concept ayant été finalement choisi, le CDT a, par la suite, approuvé sa mise en fabrication. Le dispositif en question comportait deux crochets opposés fixés au plancher du véhicule et qui, s'agrippant au fauteuil roulant par en-dessous, l'immobilisaient fixement. Plusieurs variantes ont été fabriquées et mises à l'essai sur des fauteuils roulants de différents types. De même, une spécification provisoire a été établie concernant un dispositif standardisable.

En outre, l'évaluation du point de vue ergonomique et l'analyse économique du concept ont été faites. La première soulignait l'importance de facteurs tels que le bon alignement du fauteuil roulant par rapport au dispositif d'ancrage, les méthodes d'exploitation et l'alourdissement du fauteuil; la deuxième révélait que, non seulement un dispositif universel peut ne pas être exorbitant, mais aussi qu'il peut contribuer à relever le rendement de transports semi-collectifs, au point de pouvoir espérer une période raisonnable de récupération de l'investissement.

La recherche a montré la faisabilité technique du concept envisagé. Il ne reste plus qu'à adopter une norme concernant les fauteuils roulants transportables, qui exigerait un dispositif d'ancrage universel, pour déboucher ainsi sur la solution à long terme recherchée.

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1. INTRODUCTION

In July of 1988, T E S Limited was contracted by the Transportation Development Centre to develop, fabricate and evaluate a standard interface concept for securing wheelchairs in accessible vehicles. The work is part of an overall effort to improve safety and accessibility to vehicles for wheelchair passengers, as well as to improve convenience and efficiency for the operators.

The continuing evolution of wheelchair design, which has resulted in a wide variety of sizes and shapes of wheelchair, has created a problem for accessible transportation systems.

Currently, no standardized method exists for securing wheelchairs in accessible vehicles, thus, in many cases the securement system available is not compatible with the wheelchair being transported, and system accessibility is adversely affected.

This report describes the development and evaluation of a concept for a standard interface to be used to allow wheelchairs to be secured in accessible vehicles. The report details the technical feasibility, the physical and performance requirements, an ergonomic evaluation and an economic impact evaluation of the standard interface.

2. BACKGROUND

Considerable amounts of effort and funding are being expended on research into developing accessible modes of transport to the wheelchair user. Buses, vans, trains, airplanes and taxis have been modified, and systems to allow access have been or are being developed. In addition, the terminal facilities associated with these modes of transport have been studied and are being upgraded to be accessible to the wheelchair user.

The one area which has been largely overlooked in all of this research is the wheelchair itself, especially from the point of view of the effect on the design of accessibility systems. Traditionally, due in part to the very inaccessibility of transportation systems to wheelchairs, consideration has not been given to the wheelchair as an integral part of a transportation system or vehicle. Wheelchairs have been designed for the purpose of moving mobility restricted people independently in the environment of buildings, sidewalks, parks and so on, and this they accomplish with varying degrees of success. Wheelchair design continues to move forward to provide chairs which have greater mobility on their own, greater flexibility of use (sports, etc.), and greater comfort for the user. This has resulted in a continual proliferation of new designs, with sizes, shapes, weights and general characteristics, such as wheel types and sizes, varying widely from design to design. While this continued evolution has resulted in considerable benefits to the wheelchair user, it is having, at the same time, some negative side effects particularly where transportability is concerned.

Take the example of the designer who is attempting to develop a wheelchair access system such as an elevator style lift for an intercity bus. In order to allow a detailed design to proceed, the bounds on wheelchair size, weight and style which are to be accommodated by the design must be defined and fixed, early in the program.

An unfortunate aspect of the continued evolution of wheelchairs is that by the time a design (such as the previously mentioned bus elevator lift) is completed and put into regular production, it is entirely possible that a number of new wheelchair designs, with which the lift will not operate, will be on the market and in use by a significant number of people.

This situation then immediately reduces the transportation system accessibility which has just been created after considerable cost and research effort. This same argument, of course, applies in varying degrees to all of the modes of transport which are being made accessible to the physically challenged.

Similarly, in most accessible vehicles, some sort of securement system is used to anchor the wheelchair to the vehicle to prevent movement of the wheelchair during normal vehicle manoeuvres. These systems may also be designed to restrain the wheelchair occupant and to withstand the high impact

loads associated with vehicle crashes. The proliferation of new wheelchair designs has also resulted in a corresponding increase in the number and types of securement and restraint devices appearing in the marketplace.

Unfortunately, the overall result of this recent development work is a plethora of wheelchairs, securement devices and restraint systems with no standardized means of integrating these various devices into the modes of transportation which are now being made more accessible to the wheelchair user. One solution to this ever expanding problem is the development of a standard interface for securing wheelchairs in accessible vehicles.

The current non-compatibility situation in the wheelchair/securement /restraint industry is analogous to the problems which previously faced the trucking, trailer and farm implement industries. For example, the wide divergence in highway tractors and trailers led to the development of a standard fifth wheel which is now used almost universally in the trucking industry. Similarly, the large diversity in passenger cars and recreational trailers is no longer a problem with the development of standard towing balls/adaptor brackets which are readily available throughout the country. A final example is the three point hitch which allows farm tractors and implements from different manufacturers to be coupled through a standard connection system. The solution to the problem in all of these industries was the development of a standard, low cost, interface system, which can either be designed integrally into a new piece of equipment, or easily retrofitted to an existing one.

In order to fit a standard interface to existing wheelchairs, a range of adaptor kits would be required. These kits will be designed to allow the wheelchair to operate as originally designed, however, it is foreseen that they may also provide additional strength to the wheelchair structure. Such kits will be specific to the individual wheelchair under consideration but will still conform to the standard interface specification. Such adaptor kits could eventually be available over the counter at local supply stores just as trailer hitch kits are currently available. Ultimately, by necessity of demand (or mandate of law), the goal would be to have wheelchair manufacturers integrate the standard interface into their wheelchair designs, which would mean that transportable wheelchairs would be routinely available to the mobility restricted traveller.

For any wheelchair equipped with an adaptor kit or designed with an integral interface, the securement/restraint system would be able to attach in exactly the same way and at exactly the same locations. This would eliminate the problems faced by wheelchair passengers and transportation system operators, who currently have no assurance that securement of the wheelchair will be possible in a given vehicle. Further, it should reduce considerably the time required to secure a wheelchair, and thus significantly improve the operating efficiencies of transportation systems.

3. GENERAL APPROACH

The primary purpose of this program was to establish the physical performance, ergonomic and economic criteria which would define the bounds for the design of a wheelchair interface system. In order to achieve this objective, several tasks were identified.

Comments regarding the concept of a standardized interface were solicited from interested parties such as the Coalition of Provincial Organizations of the Handicapped, the Canadian Paraplegic Association, the Office for Disabled Persons of Ontario and Veterans Affairs Canada. Further, organizations addressing the non-compatibility situation in the wheelchair/securement/restraint industry in terms of standards development and testing programs were contacted. These included the Ministry of Transportation of Ontario, wheelchair manufacturers and the International Standards Organization.

Design criteria for the standard interface were established to define the physical performance and ergonomic requirements of the standard interface. The foremost performance requirement, as identified at the project initiation meeting was that a securement system, and thus the interface, must withstand a 20 g (g = acceleration due to gravity) load in a frontal collision. This is the level that vehicle components, such as seats and seatbelts, must withstand as stipulated in federal motor vehicle safety standards.

Several design concepts were developed based on the design criteria previously established. The concepts were not limited to the interface but were expanded to encompass entire securement systems. This was necessary in order that the technical feasibility of the standard interface concepts could be determined.

Throughout this report, the conceptual term "interface" refers to the specific area in which a wheelchair interacts with a securement device. The entire securement system is comprised of this interface as well as the wheelchair side (between the wheelchair and the interface) and the vehicle side (between the vehicle and the interface).

A securement system was finally selected and subsequently approved by TDC for fabrication. Several models were fabricated and then demonstrated for a range of wheelchair types. An ergonomic assessment and an economic impact analysis of the general concept of a standard interface were performed. As well, a preliminary specification for the standard interface was developed.

Finally, the results of the program were analysed and conclusions and recommendations were formulated.

4. CONSULTATION WITH INTERESTED GROUPS

During the initial phases of the project, many interested parties were contacted including organizations for the handicapped, government departments, regulatory agencies and manufacturers of wheelchairs. The purpose of this task was to inform them of the program's objectives and to solicit their comments or suggestions regarding the concept of standardizing the interface between the wheelchair and the vehicle.

The organizations that were contacted which deal with the handicapped included the Coalition of Provincial Organizations of the Handicapped (COPOH), the Canadian Paraplegic Association (CPA), the Office for Disabled Persons of Ontario, Veterans' Affairs and the Ontario Advisory Council on the Physically Handicapped. Most of their officials expressed interest and agreement with the concept of a standard interface but no further feedback was received.

The project team visited Mr. Dave Hanes and Mr. Allan Moore who are involved in the planning of policies for the transportation of disabled and elderly persons with the Ministry of Transportation of Ontario (MTO). These representatives have investigated the standardization issue in the past and concluded that the implementation of a standard interface would not accommodate all wheelchair types (such as the sport chair and children's devices). MTO's investigation also concluded that mounting standardized connecting tabs in convenient places on the wheelchairs, combined with the Q'Straint system, would simplify the securement procedure and satisfy CSA D409 Standards. MTO has planned to conduct a testing program (excluding crashworthiness) to establish whether or not scooters can be safely transported in regular operating situations.

At the recent Ontario Workshop for Operators of Transit Services for the Disabled (held in parallel with CUTA's Fall Meeting), Mr. Murray Hattin, Chairman of the Canadian Standards Association (CSA) committee which established CSA D409 standard, indicated that further amendments to this standard had been discussed in 1987, however, CSA had not made any concrete plans as of yet to adopt the amendments.

The International Standards Organizations (ISO) TC 173, SCI, Working Group 6 "Wheelchair Restraint Systems/Transportable Wheelchairs" held a conference in Dundee, Scotland on September 19-22, 1988. This conference was attended by researchers, government agencies and manufacturers world-wide. The object of this conference was to establish a working transportable wheelchair standard, including a standard interface between the wheelchair and vehicle. At this meeting, it was proposed that the Australian Standard # 2942-1987, "Wheelchair Occupant Assemblies for Motor Vehicles" be adopted as the ISO World Standard, with modifications. At that time, no one was able to come up with any suggestions concerning a universal wheelchair securement system. The next meeting of the ISO Working Group 6 is tentatively scheduled for May

of 1989 in Holland.

The aforementioned Australian Standard specifies the requirements for restraint assemblies for wheelchairs and occupants and makes recommendations about the suitability of different kinds of wheelchairs for use as vehicle seating. This Standard allows for designs that do not require any wheelchair modifications, those in which parts of the restraint assembly are fixed to the wheelchair, wheelchairs that incorporate a child safety seat complying with AS 1754, and wheelchair frames manufactured with integral restraint components. This Standard does not apply to the securement of wheelchair users who are driving vehicles.

Several manufacturers of wheelchairs were contacted, including Braun Corporation (Indiana, USA), Fortress Scientific (Downsview, Ontario) and Everest & Jennings (Concord, Ontario), and the latter two were visited. The President of Braun, Mr. Bill Roth, stated that the concept of a standard interface was long overdue and provided the project team with a drawing of their wheelchair, which indicated the most suitable connection areas. The engineering manager of Fortress Scientific, Mr. Michael Marr, responded very positively to a universal interface between the wheelchair and vehicle and would be interested in assisting in this endeavour. He suggested that some form of shock absorbing mechanism be integrated into the interface or vehicle portion of the resulting securement system in order that wheelchairs would not be required to be designed to withstand the entire 20 g forward impact. He felt that energy absorption in the securement system would thus be a major benefit to accessibility. He also mentioned that the minimum acceptable ground clearance for the wheelchair is 7.6 cm (3 in.); any projection below 7.6 cm (3 in.) should be avoided. Finally, Fortress Scientific is currently investigating the provision of tabs on wheelchairs to which the Q-straint may be attached. The president of Everest & Jennings, Mr. John Cowan, indicated that the idea of a universal interface did not appear to be in line with current thinking. He directed us to the CSA to obtain the ISO's activities in this area.

In an effort to further explore ways in which the concept of a standard for a wheelchair interface could be implemented, contact was made with the Society of Automotive Engineers (SAE) and the Transportation Research Board (TRB), a group within the National Research Council of the USA.

The SAE have a committee dealing with transportation of the disabled in personal licensed vehicles. The Adaptive Devices Committee, through its subcommittee on wheelchair restraint systems is currently developing an SAE standard for "Wheelchair Occupant Restraint Systems". The TRB have a Committee for Transportation for the Transportation Disadvantaged (A1G02), as well as a Paratransit Committee and a Rural Transit Committee, all of which deal to varying degrees with issues concerning transportation of passengers in wheelchairs.

One of the project team attended a meeting of the TRB A1G02 Committee and presented to them the concept of a standard interface as discussed in this

report. While the committee members were extremely supportive of the concept, and might be able to provide support for further research in the area, it seemed unlikely that the TRB could be directly instrumental in the implementation of a standard, since that is not their mandate.

A meeting of the SAE subcommittee on restraint systems was also attended, to assess the potential for using that group as a method for implementing a standard. While the mandate of the committee is clearly to develop an implementable standard, their scope is limited to personal licensed vehicles, and is geared to dealing with today's problems using typical current solutions. Thus, the existing committee was not seen as a viable method for developing a standard for a wheelchair interface as envisaged here. On the other hand, the general CSA/SAE committee approach does appear to be a potentially successful way in which to develop and implement a standard, and should be considered seriously.

5. DESIGN CRITERIA

This section of the report presents the design criteria that were established to define the physical and performance parameters of the standard interface. The criteria were not limited to the interface, however, as it was necessary to explore the entire securement system environment. Hence, requirements beyond that of the interface were used to guide the development of the interface design concepts as well as to provide a means to evaluate the technical solution of the securement system.

At the beginning of this task, the team established preliminary physical and performance criteria as detailed in Appendix "A". In addition, a preliminary framework for the ergonomic considerations for the standard interface and the idealized securement system was prepared and also appears in Appendix "A".

As the concept developed, the physical, performance and ergonomic criteria evolved. The remainder of this section presents the general requirements of the standard interface and the resulting securement system, as well as the vehicle and wheelchair sides of the interface. The following is a list of these design criteria.

System

In general, the standard interface and the securement system must:

- provide a connection point(s) between the wheelchair and the securement system on the transporting vehicle, (The specification of the type, shape and location of the connection point(s) defines the interface standard),
- be compatible with surface transportation modes including buses, vans, trains and personal vehicles,
- withstand a 20 g frontal impact (Transport Canada performance criteria),
- withstand a 11120 N (2500 lbf) load applied in any direction for a period of 20 seconds (Ontario Regulation 167/81 - Highway Traffic Act),
- limit the forward, backward, rotational, lateral or vertical motion of all occupied wheelchairs to 10 mm (3/8 in.) at any point of contact with the floor (The conditions under which this criterion must be met are described in Appendix "A"),
- reduce the securement time over existing securement systems where the securement time is defined as the time it takes to manoeuvre the wheelchair into position and to secure it (desired securement time of 2 minutes or less),

- be either manually operated with minimal physical effort by the operator or passenger, or automatically activated,
- be capable of being operated by someone who is not familiar with the device,
- allow freedom of design for both the vehicle and wheelchair sides of the interface,
- allow for wheelchair misalignment (longitudinal, lateral and rotational directions) when securing the wheelchair,
- also handle misalignment due to tolerances, construction, installation, variances in tire inflation, etc., so that the interface connection can still be achieved,
- provide a system whereby a wheelchair user may align the wheelchair by himself, such as reference strips on the chair device, floors and walls,
- provide an acceptable level of dignity to the wheelchair passenger,
- provide a mechanical disconnect or manual override that could be used in an emergency if the system fails (Also, an audible warning system during securement is desirable),
- be durable, reliable and maintainable,
- be able to operate at ambient temperatures of $-40^{o}C$ to $49^{o}C$ ($-40^{o}F$ to $120^{o}F$), and
- have a life expectancy equal to that of a wheelchair (typically 10 to 15 years for standard manual wheelchairs and 3 to 5 years for electric wheelchairs, scooters and sport wheelchairs).

Vehicle Side of the Interface

The vehicle side of the interface must:

- absorb the complexity and the cost of the device instead of adding great burden of cost to the wheelchair user,
- maximize vehicle capacity,
- provide forward facing designated positions for the wheelchairs (CSA D409 Requirement),
- not interfere with the manoeuvring of wheelchairs or movement of passengers,
- be capable of being housed in a small area, especially the space beneath

the floor (approximately 125 cm x 100 x 10 cm),

- not leave any areas in the floor open, and
- be capable of incorporating a shock absorbing mechanism to reduce the load to be withstood by the wheelchair.

Wheelchair Side of Interface

The wheelchair side of the interface must:

- be adaptable to most types of wheelchairs (For this program, various wheelchair models were selected to represent typical wheelchair types. For scooter travellers, the design assumes that the passenger will be transferred to another seat and that the scooter will be secured),
- maintain a ground clearance of 7.6 cm (3 in.) or greater,
- maintain the folding feature on wheelchairs, where applicable,
- add a weight of no more than 4.5 kg (10 lb), and preferrably less for manually propelled or lightweight wheelchairs, and
- not interfere with the operation of the wheelchair or the movement of other passengers.

For the purposes of this program, the crashworthiness of the wheelchair and the passenger restraint were not considered in the actual development of the interface, however, it is realized that these issues are of great importance and that they will also need to be considered before implementation of a standard interface can proceed.

6. DESIGN CONCEPTS

This section of the report presents the design methodology, the results of the test model fabrication and the preliminary specifications for the standard interface.

The objective of the work presented was to show the technical feasibility of the standard interface concept for at least one method of activation. As stated previously, the design concept was thus not limited to the interface, but was expanded to encompass an entire securement system.

6.1 Design Methodology

The first steps in the development of interface concepts were to determine the magnitude of the loads which the interface must sustain and to investigate the optimum number and the location of connection points for the interface.

Step 1

Using the Transport Canada guideline for other automotive components such as seats and seatbelts, which stipulates that the system must be able to withstand a deceleration of 20 g in a frontal impact, loads of up to 2,698 Newtons (12,000 lbf) are possible with a combined wheelchair/occupant weight of 272 kg (600 lb). Present wheelchair designs are unable to sustain such a load at any single point, therefore, some method of distributing the load is necessary. However, this means increasing the number of connection points thereby adding weight to the wheelchair. This weight addition is undesirable especially for the manual or light weight wheelchairs. A framework which distributes the load also adds to the expense of retrofitting present wheelchairs with the interface. In addition, increasing the number of connection points makes the interface more complex, creates more difficulty in aligning the two portions of the interface, and creates the difficulty of designing a system which allows all of the connection points to be equally loaded.

Step 2

It was decided that the necessary compromise solution would be either a four point connection system or a three point connection system. The configuration would be two points, one at each rear corner and either points at the two front corners or one in the front center. This type of arrangement would spread the loads over the wheelchair and reduce the potential for bending moment loads.

Step 3

The design criterion which specifies that the interface must not interfere with the normal operation of the wheelchair guided the determination of the optimum location. It was concluded that the best locations were either at the rear or on the underside of the wheelchair. The wheelchair sides, front and top were rejected as they resulted in projections outside of the wheelchair envelope or interferred with the occupant.

The rear of the wheelchair was considered a less suitable location than the underside because it would probably mean that either a fixed bulkhead or a removable bulkhead would be required. A fixed bulkhead is undesirable as it usually hinders manoeuvrability within the vehicle. A removable bulkhead is marginally better but generally adds to the complexity of the device. The rear of the wheelchair does, however, have the advantage that for manually connected interfaces it is an easier spot for the attendant to access.

The underside of the wheelchair has the advantages of being closer to the floor therefore decreasing any potential cantilever loads and shortening the connecting linkages to the interface. As well, being underneath, the interface would maintain the aesthetic appearance of the wheelchair and at the same time not interfere with anyone pushing it. For all of these reasons the bottom of the wheelchair was ultimately selected as the optimum location.

Concept Development

After determination of the magnitude of the loads the interface must sustain and deciding upon the number and location of connection points, a number of possible interface concepts were developed.

(i) Preliminary Concepts

The initial designs were an attempt to meet not only the design criteria but also to create concepts which when combined with a securement system would be comparable cost-wise with securement systems presently being used. This meant that actuation of the interface had to be by means of a fairly simple device.

A number of concepts were developed that allowed the wheelchair user to activate the securement system by pulling on a lever or activating an electric engagement motor, however, they were rejected for any one of the following reasons: the cost of adding expensive linkage devices to every wheelchair, the difficulty of adapting the linkages to all different types of wheelchairs, the problems of alignment for engaging the securement system, and the interference of the linkages with the occupant and the normal operation of the wheelchair. The exercise of developing these concepts made it clear that, if at all possible, the moving parts of the securement system should be on the transporting vehicle, not on the wheelchair.

One advantage of this was that vehicle floors, which do not vary in shape and construction as drastically as wheelchairs, would be a simpler location to mount the moving parts of the securement system. In addition, as this is the costly portion of the securement system, it is preferable to locate it on the transporting vehicle, therefore reducing the global cost of implementing such a system.

A floor based securement system, however, would not lend itself well to self-actuation by mechanical means. One reason for this is that a lever or some type of linkage would have to project out of the floor therefore adding to the difficulty of wheelchair alignment. As well, such a lever would interfere with the use of that floorspace for other purposes. This led to the conclusion that the team should investigate interfaces with powered activation of the securement systems (ie. hydraulics, electric motors, etc.). These, of course, resulted in a securement system which was more expensive than present systems. As a result, it was decided to first investigate interfaces with securement systems which were not self-activatable. That is, an attendant or someone else would have to connect the two portions of the interface.

The concepts which were developed included variations of the 4 point belt system. The standardization would be achieved by adding standard connection points to all wheelchairs for the restraint to hook onto. In addition, retractors would be added to the floor for belt storage. Both the Ministry of Transportation of Ontario and the ISO subcommittee on wheelchair transportation are currently examining this concept. This method, however, neglects a number of important issues. First of all, a device which can be self-activated provides the wheelchair user with a far greater sense of dignity and independence. Secondly, a self-actuated device probably requires less activation time therefore minimizing down time for the transporting vehicle. Thirdly, if the wheelchair user is using his own personal vehicle he may not have anyone available to connect the securement system.

For these reasons, it was decided to develop interfaces which might require more sophisticated, self-activated securement systems, even though they would be more expensive than conventional securement systems. A number of promising concepts were developed.

One of these was a system consisting of a plate which pivots down from the wheelchair and is clamped by a brake caliper in or on the floor (See Appendix "B" for details of this method). This method was rejected, however, because linkages and a lever to actuate the pivoting plate must be added to the wheelchair and individuals with limited arm mobility would have difficulty with it. As well, to avoid the concentration of loads on one point, some framework to distribute the loads over the chair would have to be added. Further, to allow for angular misalignment of the wheelchair after positioning, some form of pivoting brake pads would have to be incorporated into the design. In summary this design required too much physical effort on the part of the wheelchair occupant and required too much alteration to the wheelchair to be acceptable. A variation from this concept (See Appendix

"B") where the activation of the caliper and plate was reversed, was also rejected for similar reasons.

Another system which showed promise, consisted of a device similar to the fifth wheel on a tractor trailer. This method would have a bracket, mounted to the floor, which would have a V-shaped groove to guide a pin affixed to the bottom of the wheelchair. This pin would be guided into a central position and locked. Upon locking, the device would pull down on the pin and therefore the chair, to create resistance to wheelchair movement. This method was also rejected because the wheelchair could be locked in position while not facing forward and linkages for lowering the pin and raising the bracket from the floor would be required. As well, it had some of the disadvantages of the pivoting plate and brake caliper method, such as single point connection and linkages.

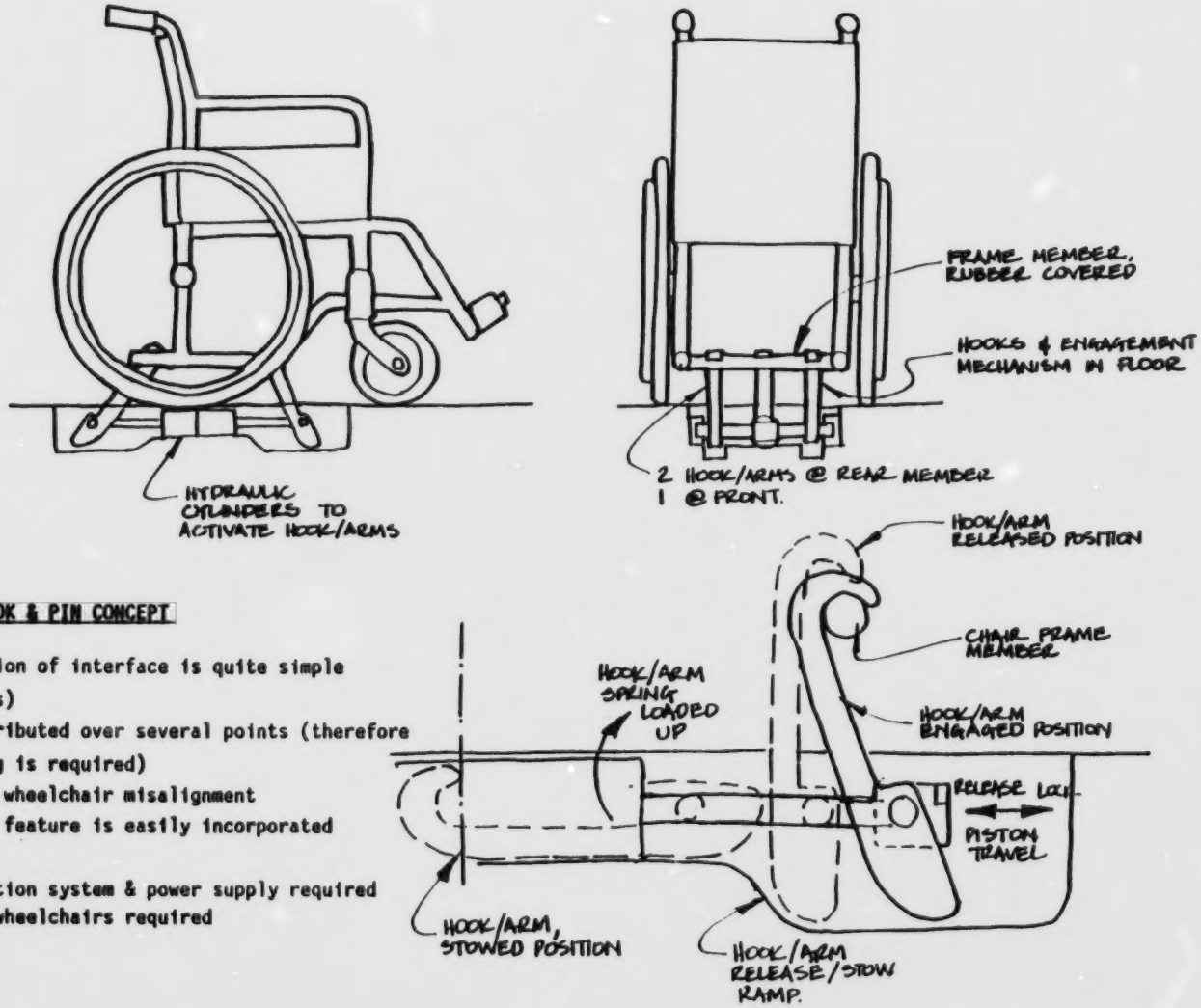
(ii) Selected Concept

Description

The securement system shown in Figure 1 was finally selected and subsequently approved by TDC for fabrication. It consists of a set of opposing hooks which rise out of the floor, secure onto mating pins on the bottom of the wheelchair, and pull down to secure the wheelchair. The actual interface on this system consists of the pins and the tops of the hooks. The hooks could be positioned by any number of methods, however, hydraulic actuation with spring loading was chosen for demonstration purposes. Layout drawings were prepared for adaptor kits for each wheelchair type investigated.

Operational Sequence

The sequence of events that takes place in securing the wheelchair with this system is as follows. The wheelchair is manoeuvred into the designated securement position. The wheelchair is aligned with the securement system (by the attendant or the wheelchair passenger) by aligning the markings on the wheelchair with the markings on the floor and wall for both lateral and longitudinal positions (See Figure 2). The interface, as specified in Figure 1, allows for 2.5 cm (1 in.) of lateral misalignment either side of centreline, 2.5 cm (1 in.) of longitudinal misalignment both fore and aft of the designated position and five degrees of angular misalignment either side of centreline. Tolerances of these magnitudes allow most people to properly locate the wheelchair. These tolerances can be increased, but at the expense of greater under-floor space requirements. Once the wheelchair is properly located, the wheelchair passenger or attendant activates a push-button on a nearby control panel. This causes the securement system to activate. Hydraulic cylinders then begin to extend. Hooks which pivot at the end of the cylinders are forced out of the floor, by means of springs, into an upright position once a certain level of cylinder extension is achieved (See Figure 3a). The hooks rise out of the floor through slots which are sealed by means of trapdoors or rubber seals. After attaining the upright position, the hooks continue to travel forward until they contact the pins which are



HOOK & PIN CONCEPT

PROS

- wheelchair portion of interface is quite simple (no moving parts)
- forces are distributed over several points (therefore less reinforcing is required)
- allows for some wheelchair misalignment
- shock absorbing feature is easily incorporated

CONS

- hydraulic actuation system & power supply required
- downloading on wheelchairs required

FIGURE 1

Hook and Pin Concept

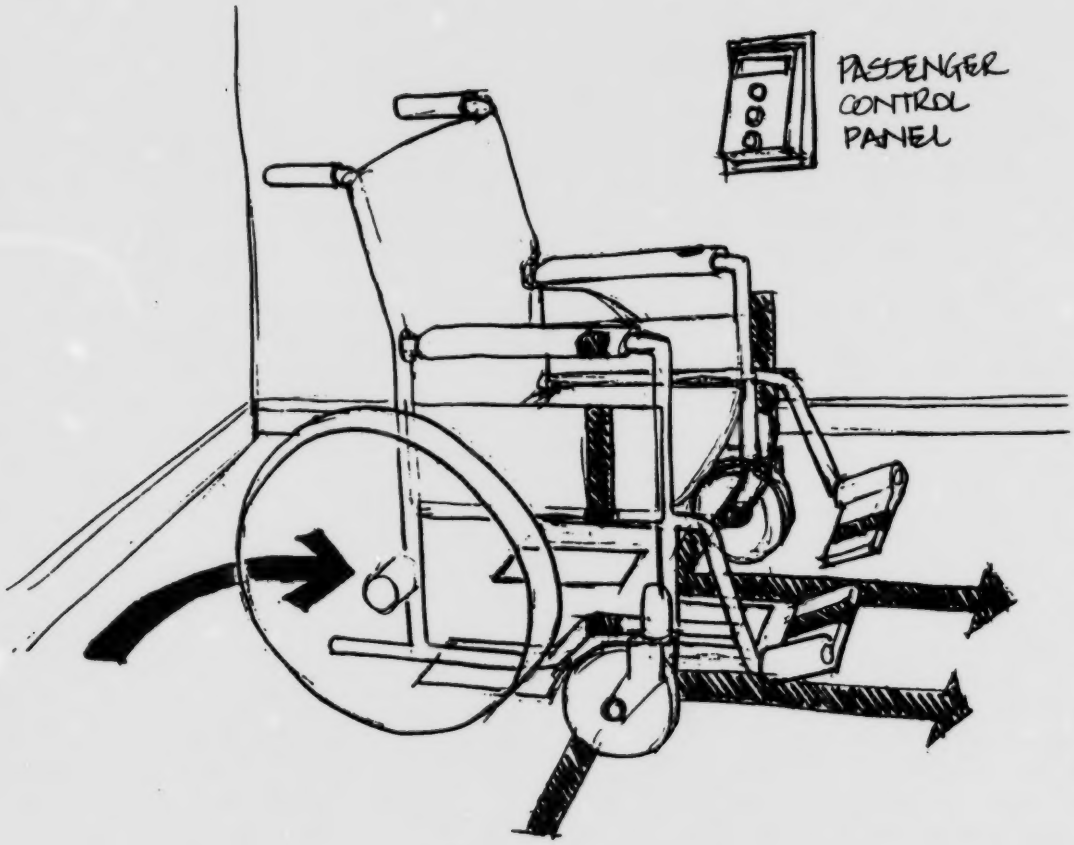
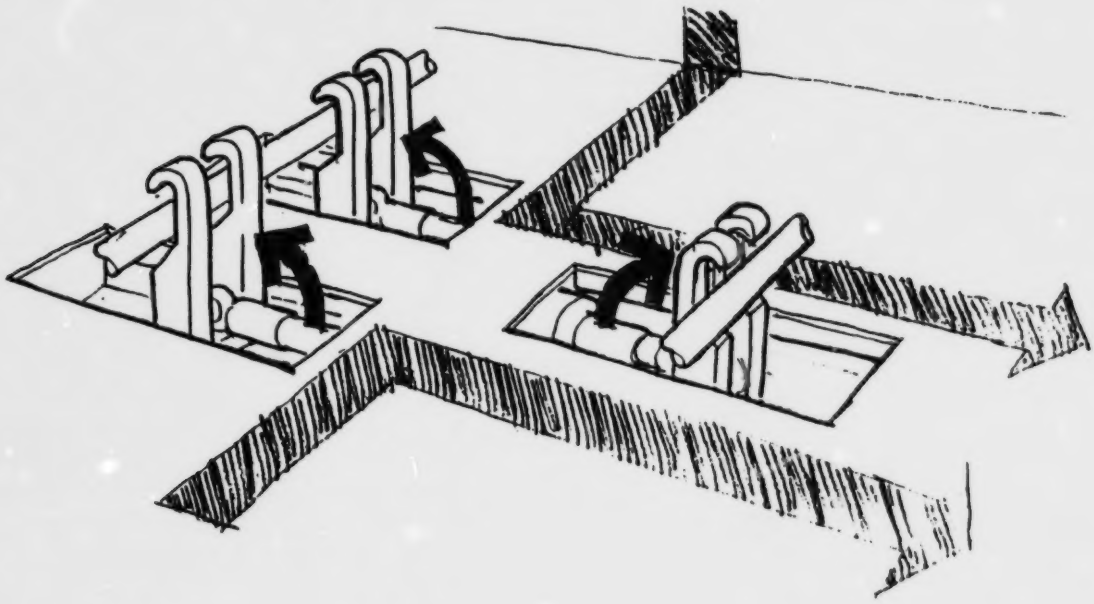
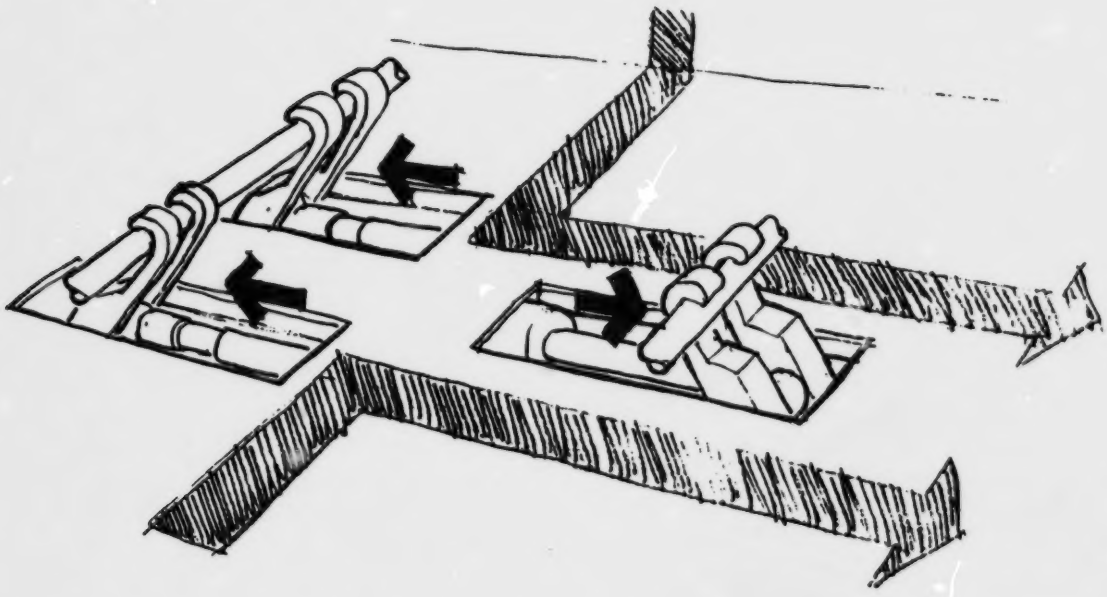


FIGURE 2
Wheelchair Being Aligned with Securement System



a) Securement System Partially Activated



b) Securement System Fully Activated

FIGURE 3
Activation of Securement System

fixed to the underside of the wheelchair. At this point, the hooks catch onto the pins and begin to pull down. The fact that there are hooks travelling in opposing directions results in the wheelchair being locked in position. Once a predetermined down-load is achieved, the hydraulic cylinders stop extending and the wheelchair is secured (See Figure 3b). To disengage the securement, the passenger or operator activates another button and the reverse process occurs.

Selection Criteria

This system was selected for the following reasons:

- it meets the requirement for the optimum number of connection points - therefore distributing the load but keeping the interface simple,
- the simplicity of the interface keeps wheelchair retrofit and design incorporation costs low,
- the additional weight to the wheelchair is kept to a minimum,
- the wheelchair occupant does not need a great deal of physical strength or upper body mobility to activate the system,
- the mechanical portions of the securement system are relatively simple, therefore, eliminating activation problems and keeping fabrication costs down, and
- this method lends itself readily to the incorporation of a shock-absorbing feature.

Summary

In summary, manually activated securement systems using mechanical linkages were investigated but rejected because of the complexity of incorporating them into the wheelchair design and their requirement for considerable physical effort on the part of the wheelchair occupant. Securement systems incorporating standardized connection points but using persons other than the wheelchair occupant to activate them were also investigated. They too were rejected for a number of reasons, the main one being the loss of control over the situation for the wheelchair occupant. This led to the development of self-activated securement systems which use power sources to achieve the connection of the two portions of the interface. This type of system is more expensive than current securement systems but offers many advantages. The final system selected meets the design criteria described in Section 5.

6.2 Test Model Fabrication

The purpose of fabricating a test model was to demonstrate technical feasibility and to evaluate the proposed interface concept in terms of the design criteria detailed in Section 5. Both the vehicle side and the wheelchair side of the standard interface were represented with the test model.

Vehicle Side of Interface

The model of the vehicle portion of the securement system was set up on a flat table. The hydraulic system was composed of a stationary powerpack, three hydraulic cylinders and two, three position control valves. The cylinders were mounted on the table with the two outer cylinders facing rearward (i.e. capable of extending rearward) separated laterally by approximately 30.5 cm (12 in.), and the inner cylinder facing frontward along the lateral centreline. Three hook assemblies were fabricated from 0.5 cm (3/16 in.) steel plate, and were installed to pivot about the rod ends of each cylinder. These pivots were guided in steel tracks to prevent any side loading of the cylinder rods.

The hook assemblies were composed of two steel hooks welded at a common pivot, and spring loaded upwards by means of a small gas spring. When activated, the hydraulic cylinders extended and the hooks rotated up out of the floor to engage with the wheelchair side of the interface (i.e. the rods). This scenario is shown for the Fortress Scientific 650 FS in Figures 4 through 7. During the retract cycle, small guides were used to rotate the hook assemblies back down into the floor to their storage position beside each cylinder.

The system was covered by a sheet of plywood to represent the transporting vehicle floor surface. Three slots were cut in the floor to allow for the travel of the hooks.

The test set up did not incorporate the most space efficient components since the emphasis was primarily on demonstrating the technical feasibility of the interface, therefore the vehicle portion of the test set up was slightly larger than what could be expected from a production securement system of this design.

Wheelchair Side of Interface

Four different wheelchair models were selected to be modified with the wheelchair portion of the standard interface. They were as follows:

- Lark, three-wheeled scooter,
- Everest and Jennings Premiere, electric powered folding wheelchair,
- Fortress Scientific 650 FS Deluxe, electric powered wheelchair, and
- Everest and Jennings Starliner, manual folding wheelchair.

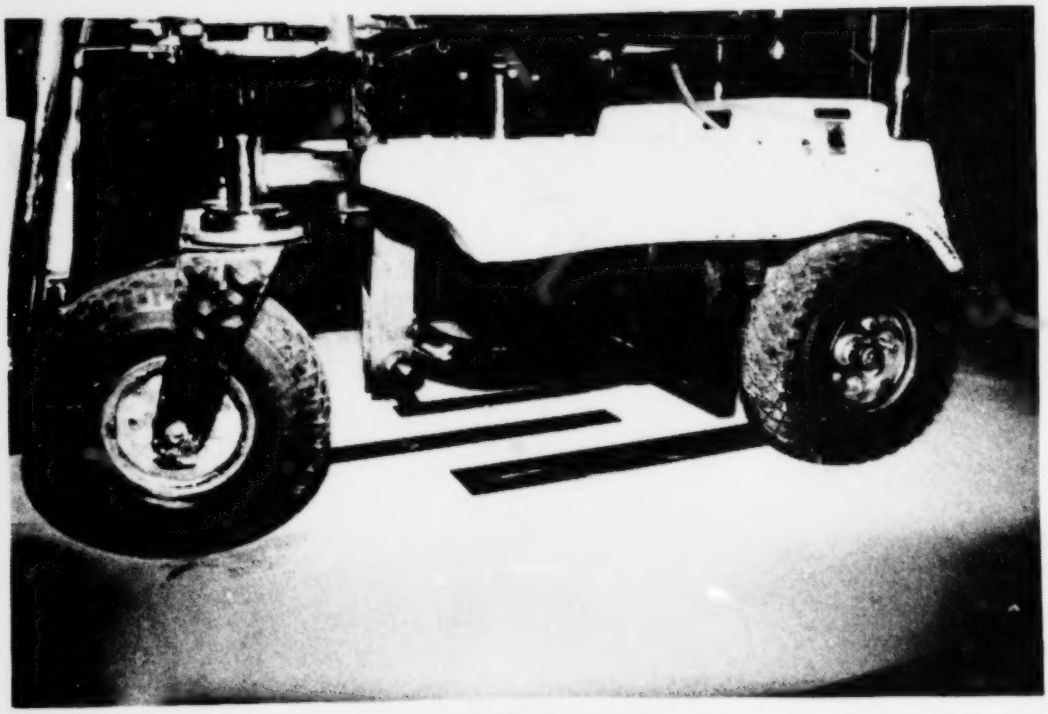


FIGURE 4

Fortress Scientific 650FS - Unsecured

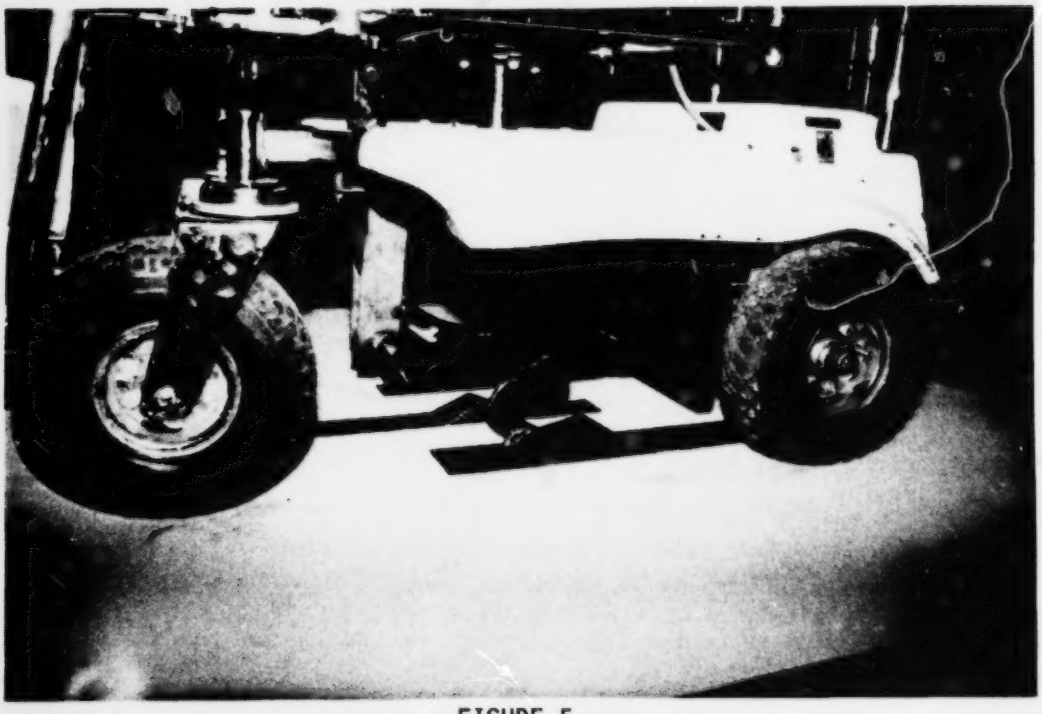


FIGURE 5

Fortress Scientific 650FS - Hooks Activated

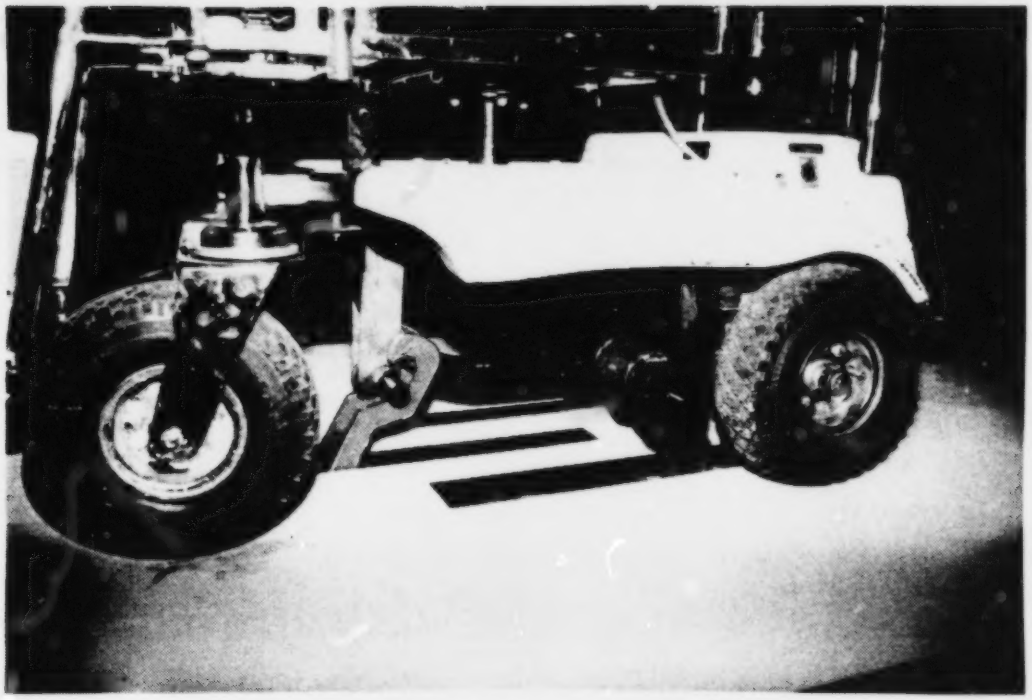


FIGURE 6

Fortress Scientific 650FS - Hooks Contacting Pins

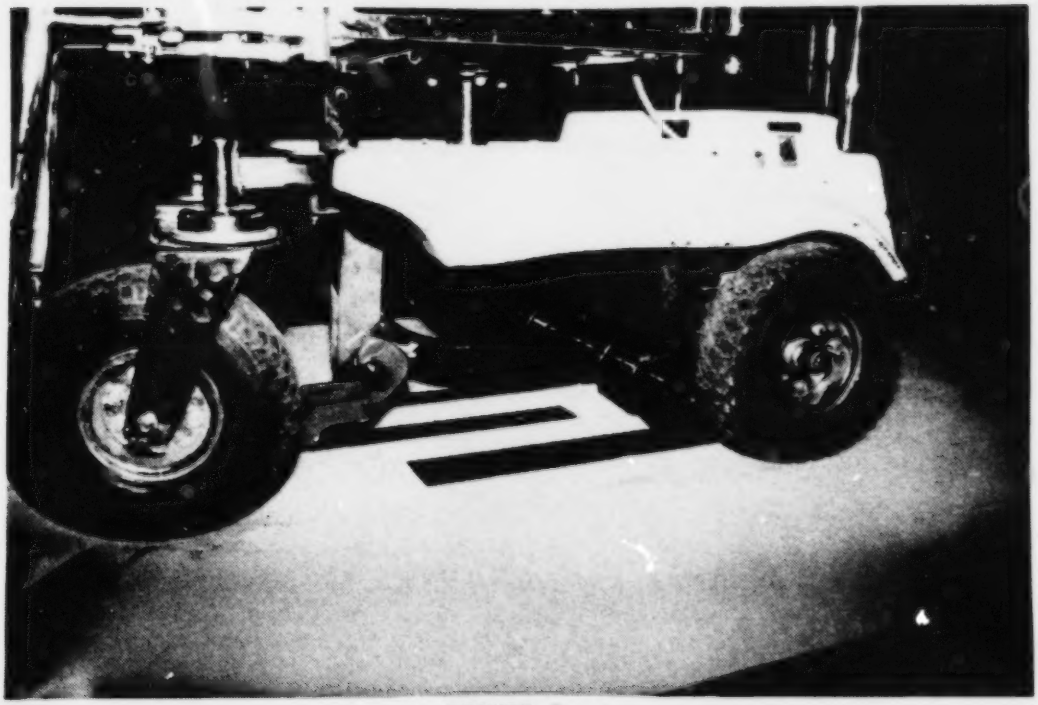


FIGURE 7

Fortress Scientific 650FS - Secured

These models were chosen to represent the variation to be expected in wheelchair characteristics such as wheelbase, clearance, tire width, frame layout and manoeuvrability.

Each wheelchair, except for the scooter, was fitted with two lateral bars, secured to the lower frame, comprising the wheelchair portion of the standard interface. (It was not possible to make such permanent modifications to the rented scooter.) The two 2.5 cm (1 in.) diameter bars were bolted to the lower wheelchair frame structures 7.6 cm (3 in.) above the floor and separated longitudinally at a distance of 3.05 cm (12 in.). The hook assemblies mounted in the floor engaged with these bars and exerted a sufficient downward and longitudinal force to secure the wheelchairs as shown in Figures 8 and 9.

Results of Trials Conducted on the Test Models

Several trials were conducted with various wheelchairs in order that the system activation, interface connection and wheelchair securement could be evaluated according to the design criteria defined in Section 5.

It was readily observed that the bar and hook spatial locations were such that all of the various wheelchairs could be secured. In each case, the wheelchairs were secured firmly to the floor thereby allowing no movement of the wheelchair. Also, the system tolerated wheelchair misalignment of 2.5 cm longitudinally both fore and aft of the centred wheelchair position, 2.5 cm laterally on either side of centreline, and 5 degrees to either side of centreline.

Automatic activation of the system provided minimal interference with the wheelchair occupant during the securement process. The securement time was determined to be about 1.5 minutes, an obvious reduction from the four point belt system securement time of approximately 5 minutes. The folding feature of the standard manual wheelchair was not affected by the addition of securement bars since the bars were hinged at the midpoint as shown in Figure 10 for the Everest and Jennings Starliner model.

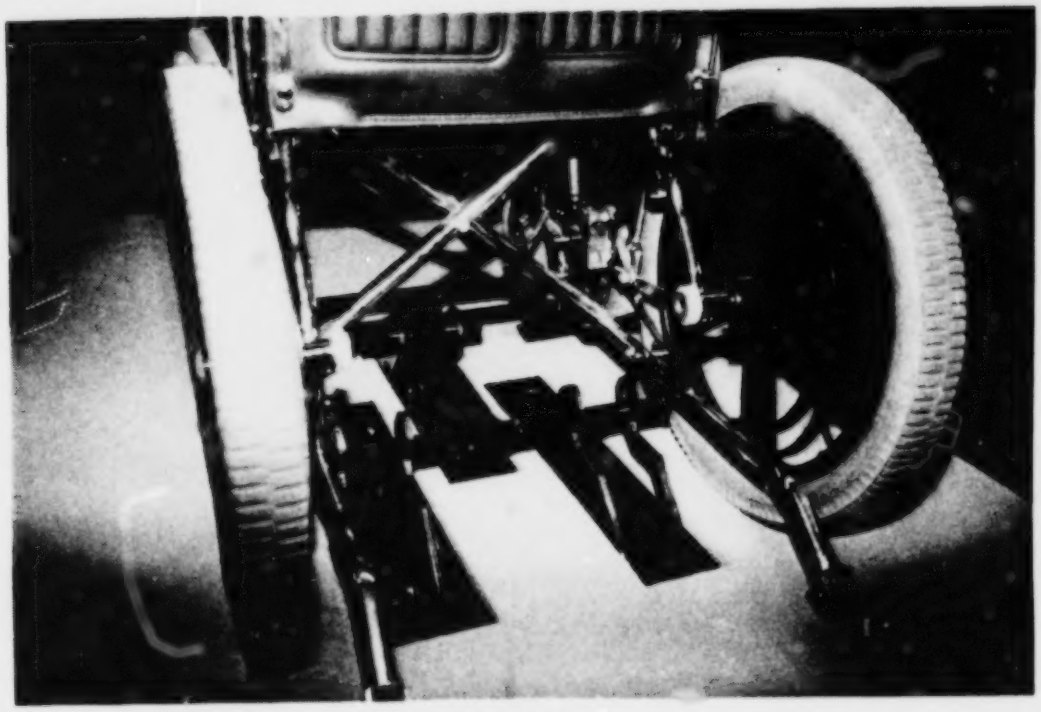


FIGURE 8

Everest & Jennings Premiere - Secured

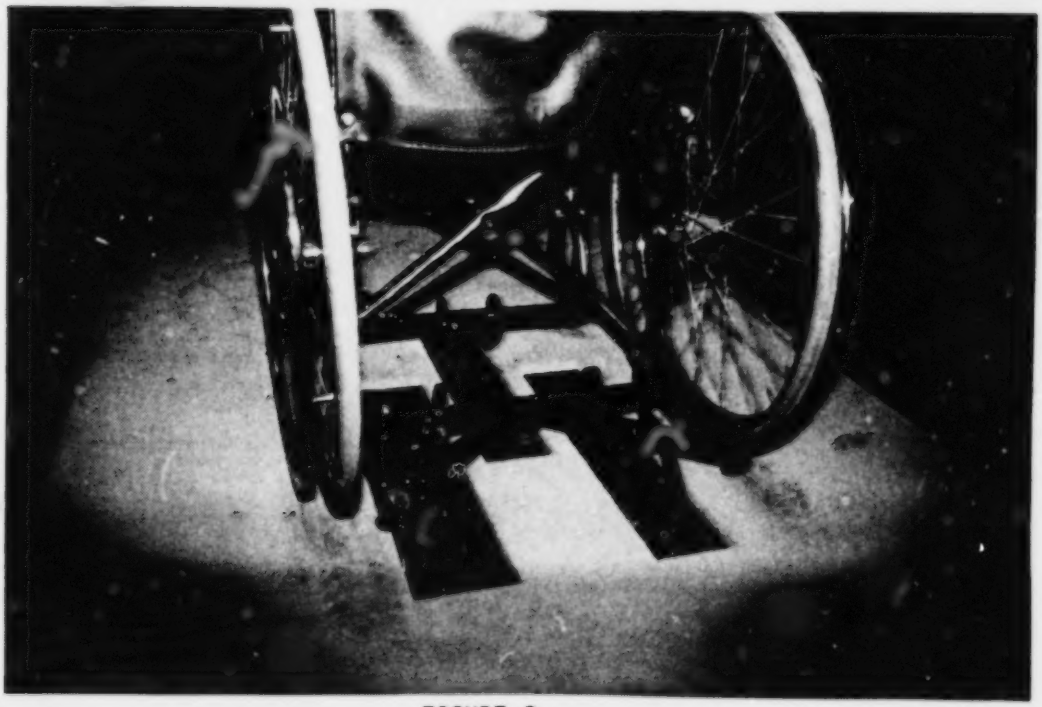


FIGURE 9

Everest & Jennings Starliner - Secured

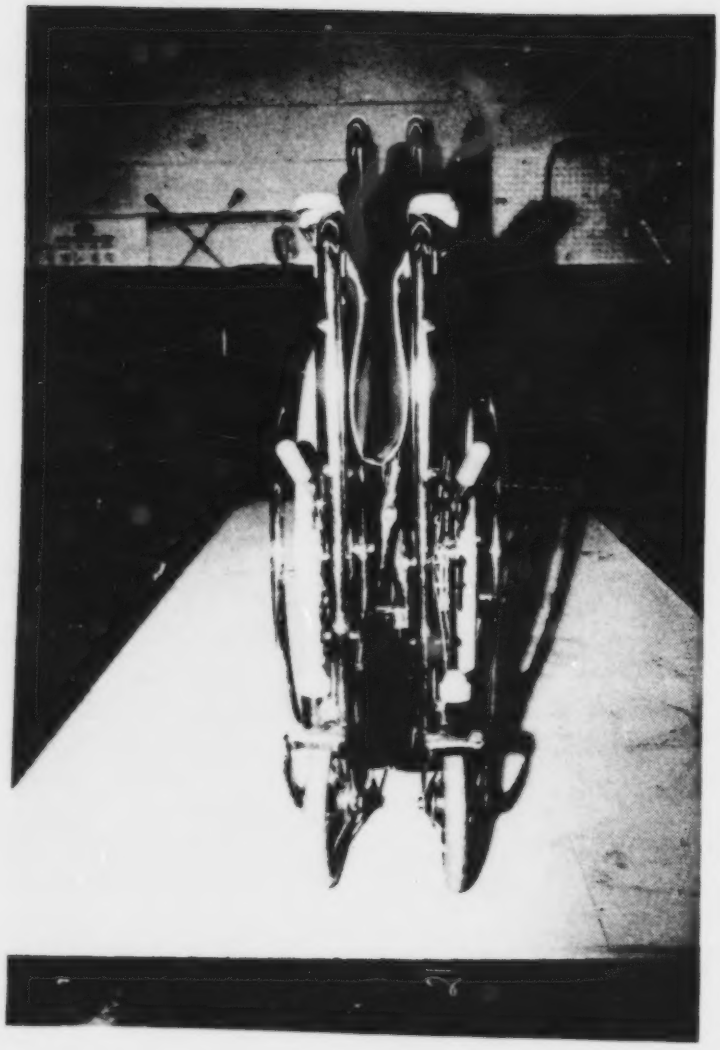


FIGURE 10
Folding Feature

6.3 Specifications for the Standard Interface

This section presents and discusses the development and design details of the specifications for the standard interface.

The specifications were developed by creating layouts of the various wheelchair types selected and determining an interface arrangement that was suitable for each of them. Parallel to this, calculations were conducted to determine the proper size and shape of the hooks and pins based on the maximum strength requirements.

The interface arrangement that was suitable for the different wheelchair types is shown in Figures 11 and 12. No exact fore and aft location for the wheelchair portion of the interface is shown. Rather, the specifications state that the interface (pins) is to be located within the outer boundaries of the wheelchair, between the front and rear wheels. This was necessary in order to simplify interface mounting due to variations in wheelchair understructure. The wheelchair portion of the interface is also based on a ground clearance of three inches.

The calculations to determine the proper size and shape of the hooks and pins are based on the maximum loading the interface could experience as well as current design practices in automotive seating and restraints. The maximum loading on the interface is achieved when the maximum possible wheelchair load of 272 kg (600 lbs) is used together with the design criterion that the interface must withstand a 20 g longitudinal deceleration. Current design practices for automotive seating and seatbelt anchorages allow for permanent deformation but not separation of the components when tested dynamically or statically to the specified loads. This is very important in terms of keeping the wheelchair portion of the interface as light as possible - especially for manually propelled wheelchairs. To allow the interface designer to make use of this, the specification provides a formula for calculating the maximum wheelchair interface load based on the weight of the wheelchair in question. Although the designer will have to maintain the overall dimensions of the wheelchair portion of the interface, he may be able to substitute tubing for solid rods on the pins and use lighter pin mounting brackets when designing for the lighter weight wheelchairs. The vehicle portion of the interface, however, will have to withstand the maximum interface loading based on the maximum wheelchair weight. The Specification, therefore provides only one load rating for this part of the interface.

As the levels of loading due to side and rear impact collisions of vehicles are still an unclear issue, the CSA D409 standard was used to determine side and rear strength requirements. This states that the interface must withstand 11,120 Newtons (2500 lbf) for 10 seconds in any direction.

Calculations to determine the interface size and dimensions assume steel to be the interface material. As high strength steel is generally only available in large quantity and special orders, the strength of steel that is commonly available was chosen.

Other important design details of the interface are the hook design and shape, hook actuation and the required levels of download the securement system must exert on the wheelchair.

The hook design shown in the interface Specification shows a dual hook system. That is, two hooks grab each pin. This arrangement was chosen because it meant that a minimum of sub-floor depth (approximately 10 cm) was required. A single hook system, although offering greater misalignment capability and simplicity, would require at least double the sub-floor depth with the style of hook actuation used in this design. However, the main reason it was not included as an option is that it would raise pin stresses to unacceptable levels with the pin length and diameter presently specified. The hooks shown in the Specification are shaped so as to remove material where it is not needed. This minimizes the space requirements for hook actuation around the pins.

Hook actuation is left to the discretion of the designer and enough space has been provided above the pins to allow for the hook to be in a vertical position before engaging with the pin. This provides the designer of the actuation system with greater design flexibility.

In order to prevent lateral movement of the wheelchair during cornering, the specification calls for a download to be applied by the securement system on the wheelchair. The sideslippage calculations were based on the CSA D409 criteria which states the acceptable level of side slippage under cornering speeds at specified turning radii.

From the aforementioned discussion, the Specifications for the Standard Interface is as follows.

Specifications for the Standard Interface

1. Scope - These specifications set forth requirements for a standard interface, which defines the connection points between a wheelchair and a securement system.

   In order to assure proper performance of the interface, standard dimensions for location of the pins on the wheelchair, size and shape of the pins and hooks, and the location of the hooks relative to the pins are included. As well, an envelope showing the minimum space requirements around the pins for proper pin and hook activation is shown. In addition to this, a formula for calculating the load levels that the wheelchair portion of the interface must withstand, the load level that the vehicle portion of the interface must withstand and the amount of download on the wheelchair that the securement system must provide are presented. Connection of the pins to the wheelchair, actuation of the hooks, and interface material selection, are left to the discretion of the designer.

2. Definition of Terms

2.1 Pin - The wheelchair portion of the interface, consisting of a round bar.

2.2 Hook - The securement system portion of the interface, consisting of a specially shaped hook.

2.3 Frontal Load - A load applied to the interface, through the wheelchair, in a longitudinal direction towards the rear of the wheelchair, parallel to the floor.

2.4 Side Load - A load applied to the interface, through the wheelchair, in a lateral direction, parallel to the floor.

2.5 Down Load - The vertical component of the preload that the hooks apply to the wheelchair when the securement system is connected.

3. Interface Location on Wheelchair - The wheelchair portion of the interface (pins) are to be located on the underside of the wheelchair, centered laterally over the longitudinal centreline of the wheelchair and located fore and aft within the outside boundaries of the wheelchair. The fore and aft location of the centre of the interface must be between the front and rear wheels of the wheelchair.

4. Interface Design Strength - The interface must be able to sustain the following loads depending on whether it is the wheelchair side or the vehicle side of the interface. Yield strength of the material is to be used for design purposes. The interface must withstand an operating temperature range of $-40^{o}C$ to $49^{o}C$ ($-40^{o}F$ to $120^{o}F$).

	Wheelchair Portion of the Interface
Frontal Load	Load = (Wheelchair Mass + 114 kg*) x 196 m/s^2
Side and Rear Loads	11,120 Newtons (2,500 lbf.)

* 114 kg represents the maximum wheelchair occupant weight.
**196 m/s^2 corresponds to 20 g.

	Vehicle Portion of the Interface
Frontal Load	53,376 Newtons (12,000 lbf.)
Side and Rear Loads	11,120 Newtons (2,500 lbf.)

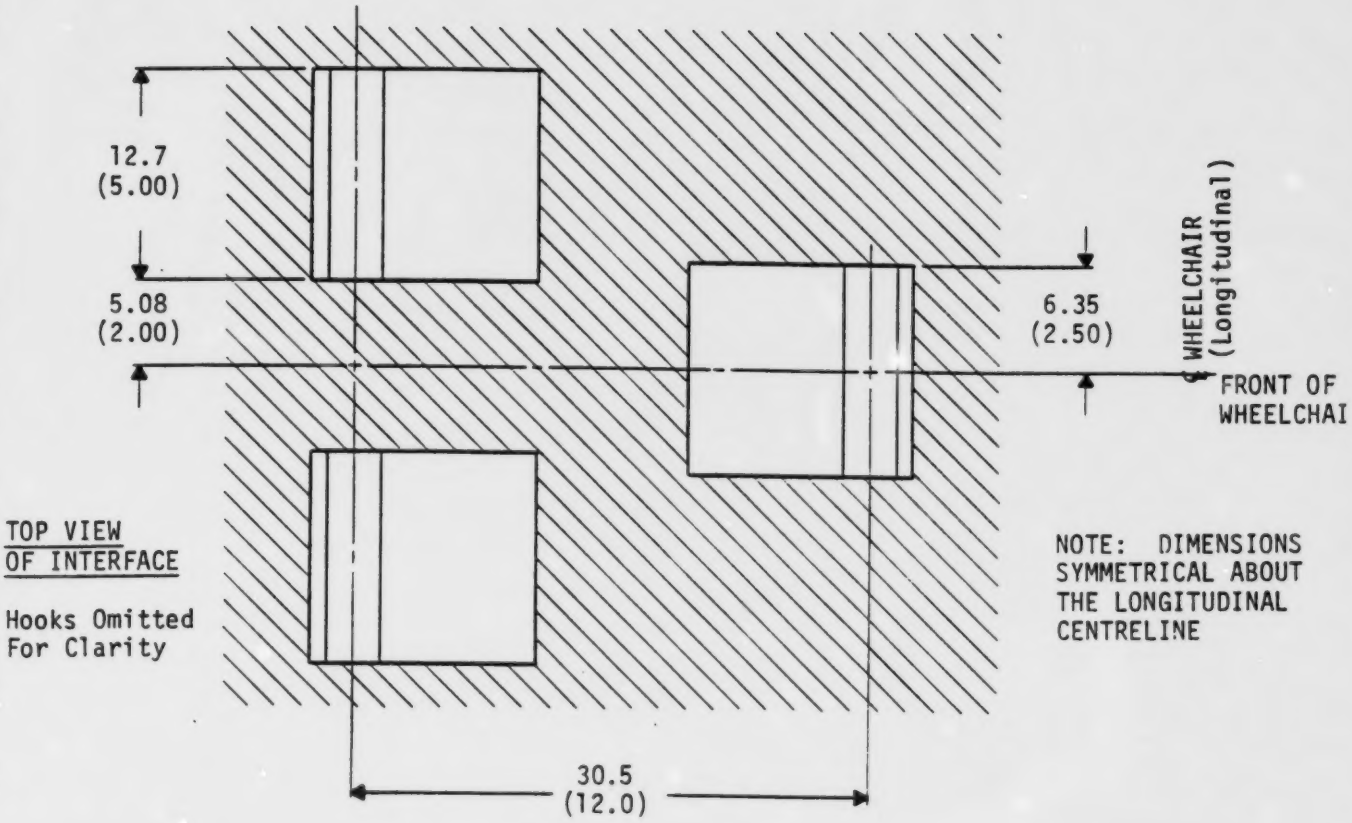
5. Interface Down Load - The securement system must apply a down-load of 89 Newtons (20 lbf.) to the wheelchair during securement.

6. Engagement Tolerances for Interface

   6.1 Hook Actuation must allow for 2.5 cm (1 in.) longitudinal wheelchair misalignment, fore and aft of the designated securement position and 2.5 cm (1 in.) lateral misalignment either side of the centreline.

   6.2 Hook design must allow for a minimum of 5 degrees of wheelchair angular misalignment either side of centreline.

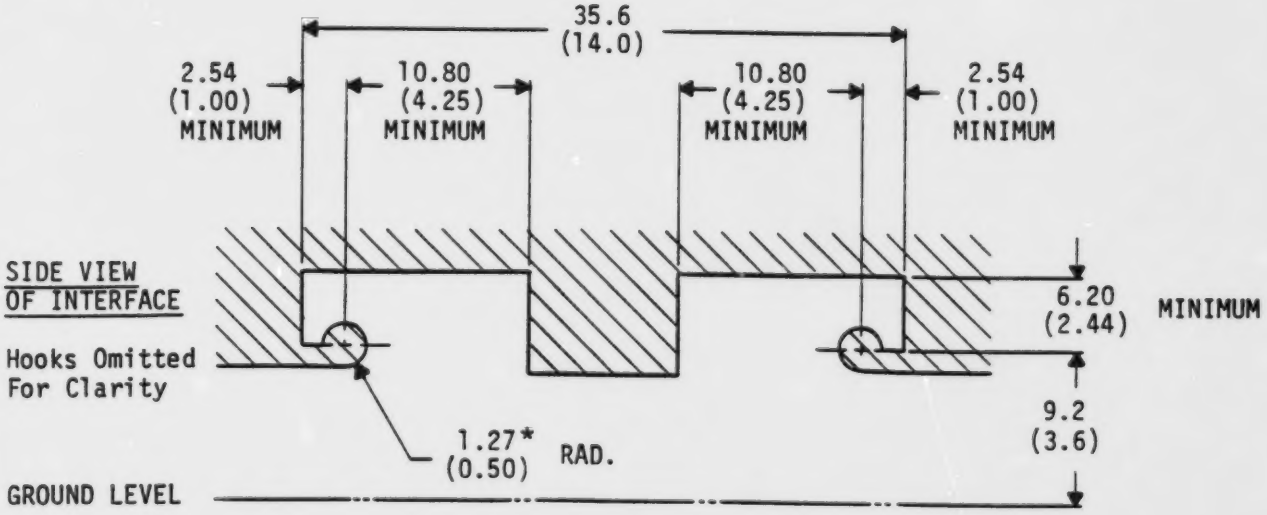
NOTE: Drawing not to scale.



TOP VIEW
OF INTERFACE

Hooks Omitted
For Clarity

NOTE: DIMENSIONS SYMMETRICAL ABOUT THE LONGITUDINAL CENTRELINE



SIDE VIEW
OF INTERFACE

Hooks Omitted
For Clarity

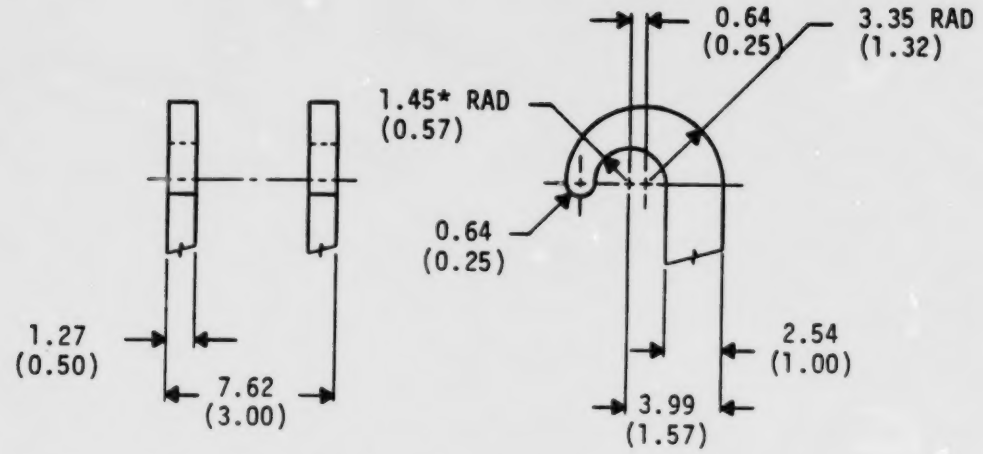
NOTE: Shaded area represents allowable envelope of wheelchair frame at interface.

NOTE: Dimensions are in centimetres (inches)

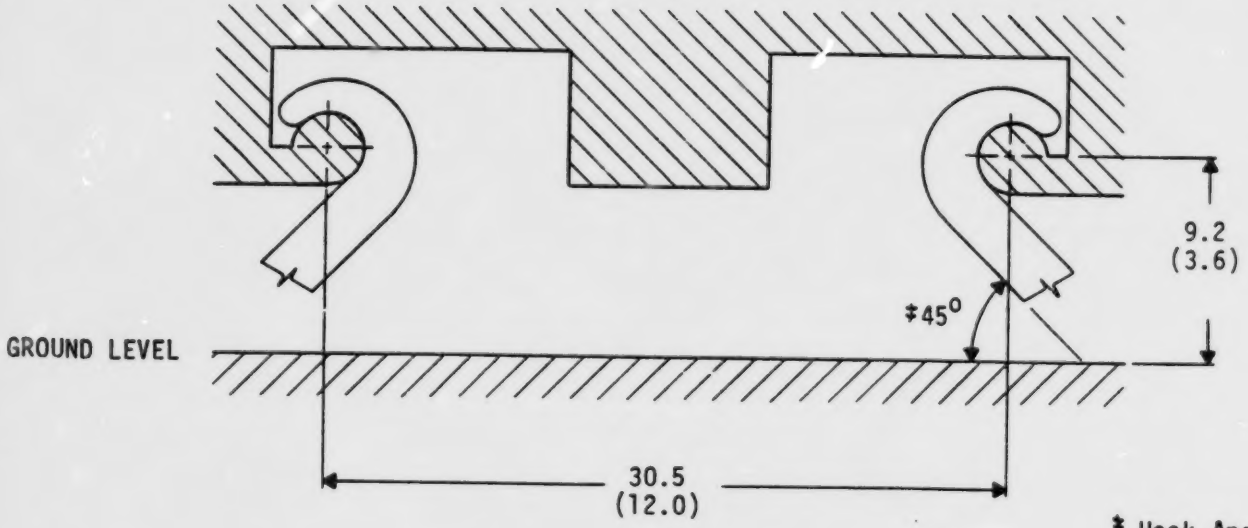
FIGURE 11

DIMENSIONS ASSOCIATED WITH INTERFACE

NOTE: Drawing not to scale.



HOOK DETAIL



* Hook Angle When Wheelchair Is Secured

Dimensions	Tolerances
X.X	± 0.3
X.XX	± 0.20
X.XX*	± 0.08
θ°	± 5°

NOTE: Dimensions are in centimetres (inches)

FIGURE 12

DIMENSIONS ASSOCIATED WITH INTERFACE

7. ERGONOMIC EVALUATION

A preliminary ergonomic assessment was undertaken by the Centre for Studies in Aging, as presented in Appendix "C". This assessment was made upon observing the test model, reviewing blueprints of suggested modifications for wheelchairs and observing a series of photographs which depicted the operation of the securement system. The purpose of this section of the report is to present the recommendations resulting from the evaluation of the test model.

Recommendations

- The design and exact positioning of reference stripes should be included as a part of any standard.
- Equipment should be marked with the origin of reference stripes in order to assist the installers.
- Suitable marker tape should be packaged with the installation instructions.
- The installer should be recommended to continue the longitudinal stripes upward on any verticle surface that prevents them from extending forward on the floor in front of the wheelchair.
- The function of the control buttons should be clearly labelled and distinguished by colour and shape. The emergency stop should be larger and should be coloured a bright red.
- A connector should be specified to provide a common interface to the controller for ancillary environmental controllers used by many disabled people.
- A quick-release mechanical disconnect for use by operators and others in an emergency should be provided with an easily perceived function, clear labelling and in a contrasting colour.
- The need to select the down-loading force to be applied to the chair is problematic and should be avoided. (NOTE: This is no longer a problem since this requirement has been eliminated from the specification.)
- A lamp should be illuminated and a buzzer should sound during the interval between full retraction and full engagement. This will provide confirmation of both states and warn of tripping hazards and of moving parts. It will also discourage operators from leaving the equipment in a partially deployed state.
- Further study is required of methods of eliminating the potential for

insensitive feet to be caught in the mechanism.

- The design of the adaptation to the wheelchair is of considerable concern, primarily because of the imposition of carrying additional weight. The adaptation must therefore be designed in the case of manual chairs to a maximum weight of five pounds if it is to gain acceptance. This concern is not relevant to powered chairs.

- The adaptation must not impede the foldability of a manual chair or the manoeuverability of the chair caused by unusually low ground clearance the adaptation may impose.

8. ECONOMIC IMPACT

An analysis of the economic impact of the standard interface concept was prepared by SYPHER:MUELLER International (SMI) Inc. This appears in Appendix "D". The intention of this section of the report is not to repeat SMI's findings in detail but rather to provide the highlights.

The economic impact analysis was divided into four stages: wheelchair ownership costs, vehicle ownership costs, transportation efficiencies and financial assistance programs.

Wheelchair Ownership Costs

- The wheelchair ownership costs were determined for adapter kits and for wheelchairs which have been designed to incorporate the standard interface (i.e. factory installed). The cost of adapter kits, which reflects non-recurring retail costs, was estimated to range from $200 to $350. The incremental retail prices of the standard interface which is integrated into the wheelchair design was estimated to vary from $50 to $200.

- The SMI study found that the greatest hardship would be imposed on those persons who own or purchase the least expensive wheelchair. It was also determined that at a cost of $200 to $350 per wheelchair the national costs to modify all existing wheelchairs will be $3.4 to $6.0 million.

Vehicle Ownership Costs

- The vehicle ownership costs were based on paratransit services although other operations to transport disabled persons exist, such as service clubs and institutions. The retrofit costs (labour and materials) to place the standard interface into existing vehicles was estimated at $2000 per designated wheelchair position. With an estimate of 2.5 positions per vehicle, the total cost for standardizing the existing paratransit fleet was $2.6 million, or 74 cents per passenger if amortized over one year.

- On the other hand, the total incremental Original Equipment Manufacturer (OEM) installed price was estimated to be $1000 per wheelchair position. Based on an average paratransit vehicle life span of seven years, and a 13% growth in ridership, an estimated 75 paratransit vehicles will be replaced and 69 new vehicles will be purchased nationally in the first year at an estimated incremental cost of $0.36 million.

Transportation Efficiencies

- The effect of a standardized wheelchair interface on the efficiency of paratransit operations was evaluated. The use of a standard interface

concept would save 3 to 7 minutes per wheelchair passenger trip over existing systems. Thus, the total time saved per vehicle day was estimated to range from 18 to 42 minutes per day (which is dependent on the vehicles utilization). The impact of these efficiency savings was assessed using three scenarios: the vehicle capacity exceeds the demand for service, the capacity meets the demand, and the demand exceeds capacity.

- Firstly, where the capacity exceeds the demand, there is no reduction in fleet size, no increase in ridership levels, and no direct economic benefits; however, the level of service offered to the passengers will improve. Secondly, where the capacity meets the demand, the fleet size could be reduced, thereby allowing savings in both operational expenses and capital budgets. Also, for a paratransit fleet the best case scenario results in an economic payback period of between two and three years and the worst case shows that no economic payback period exists. Finally, where the demand exceeds capacity, the ridership levels will increase within the current fleet size and reduce costs per passenger by $1.32 to $2.55 per ride.

Financial Assistance Programs

- The SMI study also identified and described the financial programs designed to assist disabled persons. Although these programs vary from province to province the following groups/programs usually exist: Vocational Rehabilitation of Disabled Persons Program, Vehicle Insurance Policies, Workers Compensation Board, Service Clubs, Government Agencies and Provincial Health Programs. The Vocational Rehabilitation of Disabled Persons Program (VRDP) contributes to adaptive aids needed for educational or employment purposes, including wheelchair securement systems. Should a standardized wheelchair-vehicle interface be adopted on a national basis, it is likely the VRDP would continue to contribute towards wheelchair securement devices provided they are used for transportation to access educational or employment purposes.

9. DISCUSSION

This project has demonstrated that the concept of a standard interface for wheelchair/vehicle securement systems is technically feasible. Further, the implementation of such a system appears not to be excessively costly, and in fact may even improve paratransit operating efficiencies to the point where a reasonable payback is possible. In addition, there appears to be a generally favourable attitude towards the idea amongst manufacturers, operators and users. There are, however, a number of problem areas which remain.

From a technical and operational viewpoint, the wheelchair/vehicle interface is only one part of the overall problem of safely transporting wheelchair occupants. Restraint systems for the occupant, and wheelchairs capable of surviving vehicle crash loadings are equally important concerns. In addition, reasonable design limitations in terms of parameters such as size, weight, and basic configuration for mobility aids to be transported are also important and are subject to considerable variation of opinion regarding what is "reasonable".

Any limitation on the type of mobility aid which can be transported, can be seen as denying transportation system access to the user of the mobility aid. Since, in many cases, the user of the device relies on it for day to day living, this can present a serious restriction. However, the safety not only of the wheelchair user but of the other passengers in the transportation system must be a major concern, and thus some regulation of all aspects of the system must occur.

Once the wheelchair and its user are being transported, it can be argued that the device should be viewed as part of the vehicle or transportation system, rather than as an extension of the person who is using it. It should, by this argument, then be subject to performance requirements similar to those for other components of the vehicle.

Finally, the concerns of both designers and operators of transportation systems must be taken into account. The range of devices which must be accommodated clearly affects the design of such items as transportation terminals, "wheelchair" lifts for vehicles, vehicle internal layout and so on, and also clearly affects the costs associated with operating a transportation system which is to be made accessible to the users of the mobility device.

For these reasons, it would appear that the best long term solution to the incompatibility problem which exists between wheelchairs and securement systems is to develop a standard for transportable wheelchairs. This standard would define the performance requirements and dimensional limitations for any wheelchair which would be accepted for transport by a transportation system. This would include as part of the standard for the

wheelchair, a definition of the standard securement interface with which it must be equipped. Performance areas to be addressed might include occupant restraint, crash survivability, flammability and so on.

As with any properly constituted performance standard (as opposed to a design standard), the impact on wheelchair design for aspects of performance other than those directly associated with transportation, would be minimal, and would likely be restricted to such parameters as maximum dimensions and allowable weight. Thus wheelchair designers and users would still have available a wide range of styles, features and so on within the scope of wheelchairs which would meet the transportability standard.

10. CONCLUSIONS

The concept of a standard interface for securing wheelchairs in accessible vehicles is technically feasible.

Ergonomically, a standard interface is superior to the wheelchair securement systems typically in use currently.

The efficiency of operation created by the use of a standard interface approach in public transit may be sufficient to offset the incremental costs created by the application of the standard.

11. RECOMMENDATIONS

It is recommended that the implementation of a standard governing the securement interface between wheelchairs and accessible vehicles be pursued as part of a larger program to develop and implement a standard for transportable wheelchairs.

APPENDICES

APPENDIX "A"

Preliminary Physical Performance and Ergonomic Criteria

Physical Performance Criteria for a Wheelchair Securement With a Standard Interface

PHYSICAL & PERFORMANCE CRITERIA
FOR A WHEELCHAIR SECUREMENT WITH A STANDARD INTERFACE

Objective:

Create a standard interface for connecting the wheelchair portion of the securement system to the portion of the securement system on the transporting vehicle.

Compatible with the following wheelchair types:

Manual (Folding), Powered, Scooters, Sport, etc. The restraint system for the scooter will be for securing the scooter only, not the rider.

Compatible with the following transportation modes:

All surface transport, which includes: trains, buses, vans, personal/private vehicles or any vehicle modified for transporting disabled individuals.

Design Strength Requirements:

- Must withstand deceleration of 20 g in a forward longitudinal direction (Transport Canada requirement). This equates to 8000 lbs force assuming a 400 lb combined wheelchair and disabled person weight.

- Each individual attachment point must withstand not less than 2500 lbs in a forward longitudinal direction and the total load capacity of all the attachment points must withstand not less than 5000 lbs force in the forward direction (UMTA recommendation - National Workshop on Bus Wheelchair Accessibility, Seattle U.S., May 1986).

- Must be capable of withstanding a load of 2500 lbs in any direction for a period of 10 seconds (Ontario Regulation 167/81 - Highway Traffic Act).

The wheelchair securement device(s) shall be designed to limit the forward and backward rotational, lateral, or vertical motion of all occupied or unoccupied wheelchairs to 10 mm (3/8 in.) in any direction at any point of contact with the floor when the vehicle is being operated under the following conditions, using 120 kg (250 lb) as the weight of the wheelchair and occupant.

a) full throttle acceleration on dry pavement from a standstill to 25 mph with the vehicle at its curb weight plus one occupied wheelchair

b) maximum braking from 22 mph to a standstill on dry pavement with the vehicle at its curb weight plus one occupied wheelchair

c) driving both clockwise and counterclockwise with the outer front wheel around one of the following:

i) 50 ft diameter circle at a minimum steady speed of 12 mph; or
ii) 75 ft diameter circle at a minimum steady speed of 14 mph; or
iii) 100 feet diameter circle at a minimum steady speed of 16 mph.

(CSA Standard CAN3-D409-M84)
Use of the securement device during normal vehicle operation should not cause damage to the wheelchair being transported.

At the conclusion of the aforementioned tests the securement device and components for attachment to the vehicle should show no condition of fracture, wear that would exceed manufacturer's tolerances, perceptible impairment, or other deterioration.

Interface Connection Activated By:

- Priority I: must be easily activated by driver or attendant

- Priority II: activation by wheelchair user (perhaps a signal light could indicate to the driver if the chair is properly secured).
  - degree of disability still to be defined
  - a person who is not familiar with the device should be able to implement the device easily

Allowable Interface Connection Time:

- Maximum is 5 minutes.
- Goal is less than 1 minute.

(Recommendations of National Workshop on Bus Wheelchair Accessibility, Seattle, May 86)

Emergency Release:

- The interface connection must have some form of emergency quick release or override if normal connect/disconnect procedures require large amount of time (?) or are complex in nature.

- The goal is to have the wheelchair user able to activate the emergency disconnect.

Fail Safe Requirement:

- Any power assisted locking (connecting) device shall have some method for maintaining the wheelchair securement in the event of a power failure.

Other Design Considerations: (In descending order of importance)

- Easy to operate (includes ergonomic considerations)
- Provide a sufficient level of dignity to the passenger
- Must not interfere with the normal operation of wheelchair

- Must not interfere with the normal operation of the vehicle (i.e. loading of chairs, passenger movement, utilize a minimum of floorspace, structural attachment to chassis)
- Cost competitive with present securement systems, for both purchase and installation
- An interface will presently require a kit to adapt to the chair, the chair attachment points should not sacrifice chair structural strength under impact in order to achieve standardization
- Interface must have the ability to handle misalignment due to
  - tolerances, construction, installation, etc.
  - tire inflation or deflation (which may alter height of wheelchair)
  - minor damage
- Securement device must not attach to the wheels on the wheelchair
- Wheelchair orientation must be forward facing
- Lightweight
- Durable (life expectancy with normal servicing should be equal to at least life expectancy of standard bus - 12 years)
- Should not pose any sharp edges or protruding surfaces that will scratch walls, etc.
- Protection against vandalism

Preliminary Framework for Ergonomics of a Standard Wheelchair Securement Interface

Prepared by
Heron Ergonomics

August 1988

Preliminary Framework for Ergonomics of Standard Wheelchair Securement Interface

Introduction

This report presents a schema that is meant to act as an immediate guide to design decision-making at this conceptual stage of development, as well as a framework that will form the basis of ergonomics input as the product develops. Its present structure and content are based on information that is available at this point in time, and as it is understood. As the product develops and information about specific design features becomes available, the structure may be modified somewhat while the content will become much more detailed and incisive.

A preliminary version of this framework follows an outline of its components.

Basic Categories of Effects

The basic units of ergonomics analysis are person/system interactions. For purposes of this project, effects of all possible person/system interactions can be subsumed under four major categories, namely, Mental Load, Physical Load, Psychological Factors, and General Safety.

> Mental Load is related to sensory, perceptual, and cognitive (i.e. in sum, information-processing) requirements of any task involved in use of the product. Violations of human capacities in these respects can translate into system inefficiency, error, or accident.
>
> Physical Load is related to the physical effort required by a task and/or stress to parts of the musculoskeletal system brought about by the need to assume biomechanically awkward stances, especially under conditions of force. Many of these actions can produce microtrauma which may appear insignificant at the time; however, if the activities are carried out repetitively, effects can accumulate to produce painful and seriously debilitating repetitive strain injuries (RSIs) or cumulative trauma disorders (CTDs).
>
> Psychological Factors refer to sensations, perceptions, feelings, and attitudes associated with the product as a whole. Such factors as sensation of movement and sense of security, comfort, and dignity are relevant. Attitudes may relate to the costs and durability of the product, its aesthetic appearance, information about its safety

properties, and social and legislated requirements regarding its use. Psychological factors are mainly relevant to dealers and consumers and, hence, impact greatly on marketability.

General Safety covers safety implicationsof Mental and Physical Load, as well as other concerns not logically associated with these categories.

Categories of Persons Interacting with the System

There appear to be five general categories of persons who will interact with the proposed product, as follows:

Manufacturer of the Product

Wheelchair Manufacturer, Dealer, and Servicer

Carrier Personnel: (a) for Installation of securement component

(b) for Engagement/release of interface component

Wheelchair Occupant

Provisional Framework of Ergonomics Considerations

The two sets of categories are combined in a framework that is intended to encompass systematically the ergonomics effects of all person/system interactions relevant to the product. In this formulation, details that need to be considered are set out for each type of System Interactor under Mental Load, Physical Load, and Psychological Factors. Because of its importance and pervasiveness, General Safety is treated as a separate component.

(1) Product Manufacturer (of securement and interface components)

Mental Load
- readability of engineering specifications and drawings
- interpretability of design and assembly instructions
- simplicity of operations during assembly, packing, etc..

Physical Load
- absence of biomechanical problems during tooling, assembly, packing, etc.

(2) Wheelchair Manufacturer, Dealer, Servicer (re installation/ removal, storage, unpacking, of interface component, and servicing of chair)

Mental Load
- interpretability of instructions
- compatibility of logic of operations with human sensory, perceptual and cognitive capacities and dispositions
- fewness of parts and operations
- simplicity of operations
- feedback re correctness of operations (visual, auditory, tactual, kinaesthetic)

Physical Load
- manipulability of parts by fingers (shape, texture, size NB)
- absence of adverse biomechanics (re fingers, wrists, spine, etc)

Psychological Factors
- reaction of management to legislated use
- concern re saleability to wheelchair owners and carriers

(3) Carrier Personnel

(a) Installation of Securement Component in Vehicle

Mental Load
- as for (2)
- compatibility with occupant restraint installation

Physical Load
- as for (2) - include cleaning of vehicle in concerns

(b) Engagement/Release of Interface to Securement Fixture

Mental Load
- as for (2)
- clearly perceptible feedback re satisfactory engagement
- clearly perceptible signal re need to activate emergency release
- clearly defined procedure for de-activating fail-safe system, if necessary

Physical Load
- as for (2)
- absence of gait disturbance due to protrusion of interface into stride space
- manoeuverability of wheelchair into and out of engagement position (spacing of securement installations NB)
- reachability of emergency release (button, system, ?)

Psychological Factors (pertinent to Carrier Management)
- reaction to legislated use
- ease of conversion (if new system not compatible with old)
- cost of conversion (installation and maintenance)
- safety responsibility issue (question of who is responsible may well become an issue if use legislated)
- negative backlash regarding the disabled (could occur if carrier sense of inconvenience over-rides social desirability factors)

(4) **Wheelchair Occupant**

Mental Load
- easy perceptibility of how wheelchair should be manoeuvered into and out of engagement positio (if interface at rear, guidelines on floor for centering chair may be needed)
- simplicity of engagement operation (review of systems in some drive-from-a-wheelchair automobiles may be helpful)
- clearly perceptible feedback re satisfactory engagement (auditory, kinaesthetic, visual?)

Physical Load
- manoeuverability of wheelchair into and out of engagement position (spacing of securement installations NB)
- comfort re accompanying restraint system (design of which may be constrained by design of interface system)

Psychological Factors
- sensation of movement

- sense of security (physical criteria for testing securement properties of interface system may be insufficient to avoid wheelchair occupant's perception of insecurity deriving from kinaesthetic feedback from wheelchair on turns etc. - this was observed in multi-purpose vehicle)
- knowledge of personal safety in event of impact (eg. only the chair is secured by system, and this only when chair in good shape - passenger may not know restraint system and headrest needed for same degree of protection available to a passenger in a modern personal vehicle)
- conspicuity of engagement procedures, of wheelchair configuration when secured in vehicle, and of the interface itself as part of the wheelchair
- aesthetics (system should blend with general decor of vehicle and, as far as possible, with the design of the wheelchair)
- durability of product (is there risk of damage to interface when wheelchair thrown into trunk of a taxi or belly of a plane when travelling?)
- provision of choice (try for easy removability of interface when wheelchair occupant not travelling with carrier, and for independent engagement of interface with securement by wheelchair user - latter may need to be restricted to those with good upper limb capability)

(5) **General Safety Considerations**

The following should be avoided:

- rough surfaces or sharp protruding parts which risk injury to fingers
- protrusion of parts of securement system into movement space of passengers and others within the vehicle
- protrusion of parts of the interface system into stride space of wheelchair pusher, or into operation space of wheelchair handler (eg. in folding, unfolding, or lifting chair)
- creation of mental load through violation of principles of human information-processing
- conflict between fail-safe and emergency release systems (eg. when power failure is due to a vehicle accident)
- installation spacing that hampers evacuation in event of emergency

Comments

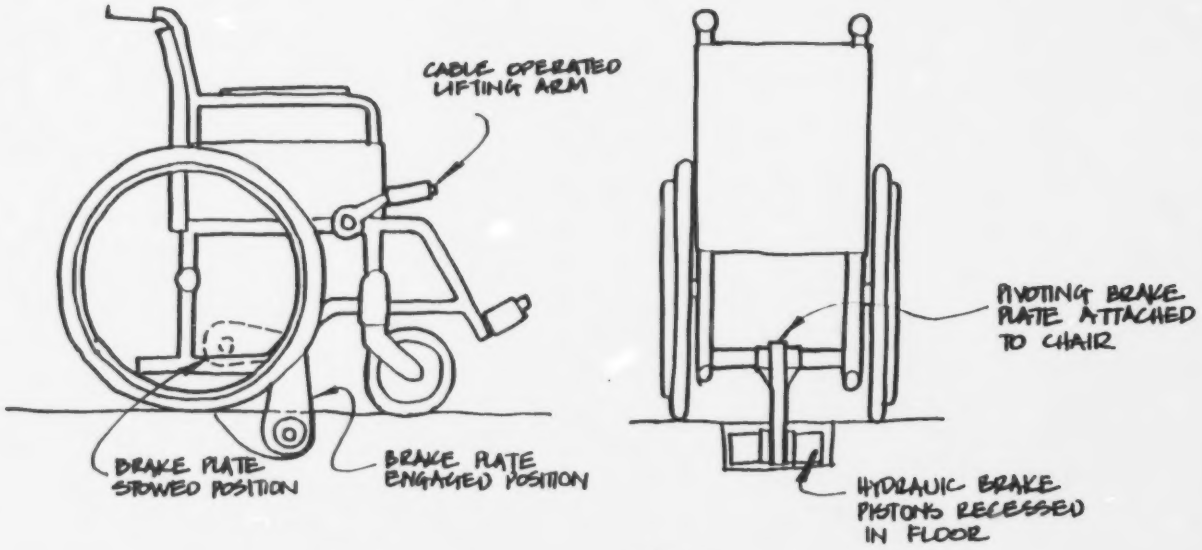
Some comments regarding the wheelchair attendant's task are relevant. A recent ergonomics analysis of a paratransit van operator's tasks indicates that such individuals are subject to a great deal of mental and physical load. Mental load arises because of a plethora of small routinized task elements in carrying out wheelchair loading and unloading operations. Typically, elements for tasks of this nature are stored in memory in a specific sequence and operated as a program. However problems arise when distraction disrupts the program, as a consequence of which forgetting occurs or task elements are carried out inefficiently. As these effects have serious implications for safety, it will be important for future technology to simplify the operator's task as much as possible - reducing the number of elements to a minimum, designing operations so as to be completely compatible with human information processing characteristics, and providing feedback regarding the satisfactory completion of operations.

Physical load to paratransit operators arises because of the need to assume biomechanically awkward postures under conditions of resistance. To the extent that such operations are carried out on a repetitive basis, paratransit operators appear to be prime candidates for RSIs or CTDs which are receiving a great deal of attention in current ergonomics and OH&S literature. As development of these injuries is analogous to a titration experiment in which small increments of the chemical have no apparent effect on the liquid until a certain point is reached, their daily effects are often not taken seriously. However, because ultimately the outcome, apart from a reduction in the quality of the victim's life, can be costly for society both in terms of medical care and reduced productivity, ergonomics approaches which will alleviate these effects are desirable.

August 15, 1988.

APPENDIX "B"

Preliminary Design Concepts


CABLE OPERATED LIFTING ARM
BRAKE PLATE STOWED POSITION
BRAKE PLATE ENGAGED POSITION
PIVOTING BRAKE PLATE ATTACHED TO CHAIR
HYDRAULIC BRAKE PISTONS RECESSED IN FLOOR

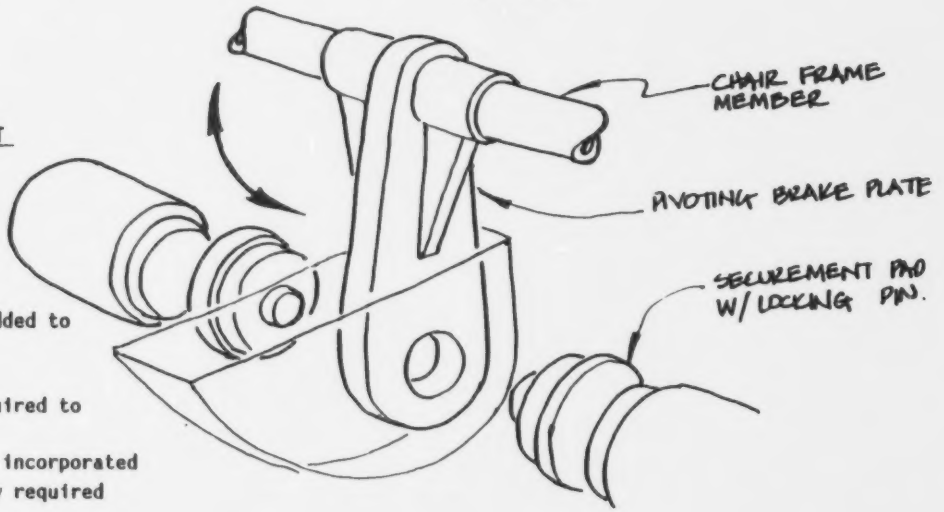
BRAKE CALIPER & PIVOTING PLATE CONCEPT

PROS

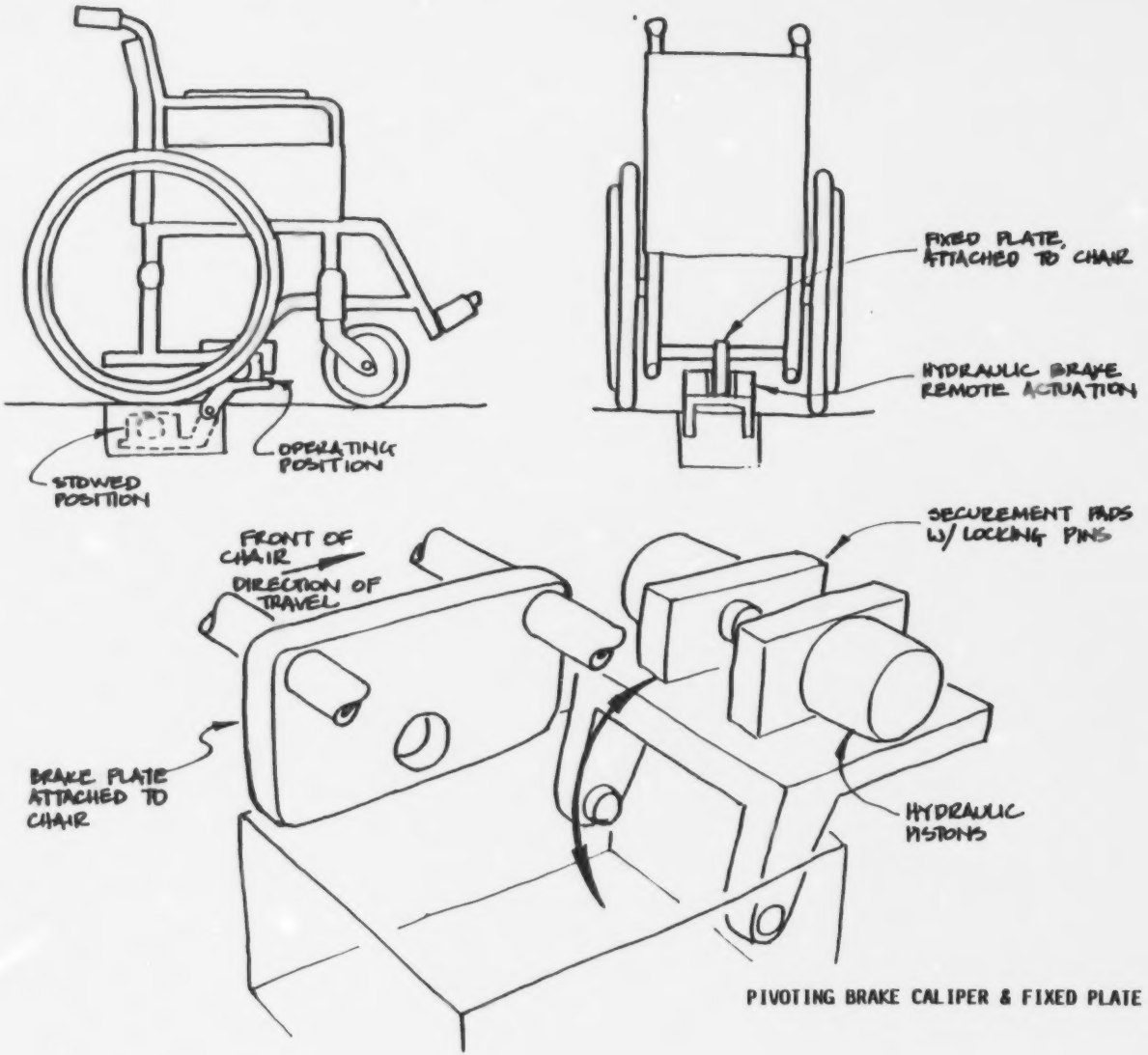
- relatively simple (few moving parts)
- allows for some wheelchair misalignment
- positive mechanical locking device

CONS

- linkages and actuation devices must be added to wheelchair
- forces are concentrated at one point
- turntable or pivoting brake calipers required to allow for angular misalignment
- shock absorbing feature is not as easily incorporated
- hydraulic actuation system & power supply required



Brake Caliper & Pivoting Plate Concept



Pivoting Brake Caliper & Fixed Plate Concept

APPENDIX "C"

Ergonomic Evaluation of Standard Wheelchair Interface,
Centre for Studies on Aging, January 1989

ERGONOMIC EVALUATION OF A WHEELCHAIR STANDARD INTERFACE

prepared for T E S Limited

by Geoff Fernie, Ph.D. P.Eng., C.C.E.
Centre for Studies in Ageing
University of Toronto

January 13, 1989

January 13, 1989

ERGONOMIC EVALUATION OF THE TES WHEELCHAIR STANDARD INTERFACE

RECOMMENDATIONS

1. The design and exact positioning of reference stripes should be included as a part of any standard.

2. Equipment should be marked with the origin of reference stripes in order to assist the installers.

3. Suitable marker tape should be packaged with the installation instructions.

4. The installer should be recommended to continue the longitudinal stripes upward on any verticle surface that prevents them from extending forward on the floor in front of the wheelchair.

5. The function of the control buttons should be clearly labelled and distinguished by colour and shape. The emergency stop should be larger and should be coloured a bright red.

6. A connector should be specified to provide a common interface to the controller for ancillary environmental controllers used by many disabled people.

7. A quick-release mechanical disconnect for use by operators and others in an emergency should be provided with an easily perceived function, clear labelling and in a contrasting colour.

8. The need to select the down-loading force to be applied to the chair is problematic and should be avoided.

9. A lamp should be illuminated and a buzzer should sound during the interval between full retraction and full engagement. This will provide confirmation of both states and warn of tripping hazards and of moving parts. It will also discourage operators from leaving the equipment in a partially deployed state.

10. Further study is required of methods of eliminating the potential for insensitive feet to be caught in the mechanisms.

11. The design of the restraint adaptation to the wheelchair is of considerable concern, primarily because of the imposition of carrying additional weight. The adaptation must therefore be designed in the case of manual chairs to a maximum weight of five pounds if it is to gain acceptance. This concern is not relevant to powered chairs.

12. The adaptation must not impede the foldability of a manual chair or the manoeuverability of the chair caused by unusually low ground clearance the adaptation may impose.

INTRODUCTION:

TES Limited of Ottawa have prepared a prototype of a suggested standard interface for securing wheelchairs in accessible transportation. This work was conducted for the Transportation Development Centre of Transport Canada. The project plan called for a full ergonomic assessment to be undertaken by Heron Ergonomics. The task was reassigned in mid-November of 1988 following the transfer of Dr. Ruth Heron to employment with the Transportation Development Centre.

This ergonomic assessment is based upon observations made during a visit to TES when the operation of the prototype was demonstrated. The prototype was mounted within a plywood sheet that simulated a vehicle floor. It was at tabletop height and the demonstrations were restricted to observing the function with unoccupied wheelchairs. Control switches, manual backup operating systems, and instructions for users and installers were not available for examination.

Blueprints of suggested modifications for wheelchairs were provided, together with sketches illustrating the mode of operation. A series of photographs was provided showing the sequence of operation of the prototype with a Fortress powered chair and with a folding manual chair. These photographs also illustrated the capability of the system to deal with moderate misalignments of the chair and illustrated a prototype configuration of a folding interface that would not inhibit the folding operation of the manual chair.

Time and resources did not permit a full ergonomic evaluation of the prototype based upon experiment. A proper ergonomic evaluation would have included trials of the prototype in, at least, a simulated vehicle environment with a representative sample of disabled users and of vehicle operators.

RESULTS OF THE ASSESSMENT:

The User:

In order to use the system the following steps are required:

1. correctly position the chair;
2. operate the securing mechanism;
3. check that the chair is secured correctly;
4. Operate the system to disengage.

Positioning the Chair:

The prototype allows the chair to be laterally misaligned by up to 25 mm from the centre line and has a range of acceptable longitudinal positioning of 50 mm. An angular misalignment of approximately 5 degrees is permissible.

There is a suggestion in some of the sketches that lines might be painted on the floor and walls of the vehicle to act as reference markers. These lines were simulated in the laboratory by tape stuck to the floor and walls. An able-bodied researcher had no difficulty learning to position a manual chair within the required tolerance. He related the stripes to reference features on the chair. It is clear that the exact positioning and design of the stripes should be a part of any standard to that users may apply the same reference strategies in different vehicles. The apparatus should be marked with the origins of the lines to assist the installer and appropriate marking tape should be provided. The lines on the floor, in particular, might be quite difficult to follow because of being hidden by footrests, long skirts, etc. Consequently, it is recommended that these lines be extended upward, so far as possible, on any vertical surface of the chair.

TES has suggested that larger misalignments could be managed by fitting a pressed sheet pan to the underside of the wheelchair with grooves to guide the hooks toward the securement rods. The hooks would be equipped with a swivel joint to facilitate self-alignment. This option might be worth considering for powered chairs provided that the swivel joint did not decrease the effectiveness of the system when used with manual chairs where the pan would be impractical.

Operating the Restraining System:

The illustrations show a three button control panel for electrical operation. Presumably one button would be labelled "engage", the second would be "disengage" and the third would be "emergency stop" for the mechanism. It would be important to apply the usual ergonomic principles of using colour and shape combined with labels in the form of clear symbols to distinguish the buttons. In particular, the emergency stop button should be very prominent. The control panel would obviously require positioning within easy reach. It might be helpful to specify a standard connector so that customized interfaces could be produced that could be simply plugged into this panel. This would facilitate its operation by the various forms of environmental controllers that are used by people lacking upper limb function.

Henry Vietinghoff, project engineer at TES, has estimated that a hand-powered system would require a pumping effort ranging from about one or two pounds to drive the hooks to a maximum of ten pounds force on the last stroke to achieve the attachment. The number of strokes could be as high as twenty-four. This level of effort would obviously be achievable by a manual wheelchair user provided that the pump handle is positioned appropriately.

There is no mention of a mechanical disconnect that could be used in an emergency if the electrical or mechanical hydraulic systems fail. One would envisage a pin or similar device that could be used to disconnect the hooks from the mechanism. Ideally, this pin should be able to be disengaged by the wheelchair user, but that may present unreasonable technical complexity. It should be brightly coloured and clearly labelled for use by the operator or an untrained passerby in an emergency.

Check that the Chair is Secured Correctly:

The control panel is to be equipped with a switch to select the appropriate downward force that is to be applied by the system depending on the wheelchair type. Insufficient data are presently available to assess the ergonomic factors related to this switch. If it is only necessary to distinguish between manual chairs and electric chairs, then that would seem an easily understood task except in circumstances where, for example, an electric motor unit is provided as an add-on to a manual chair. The consequences of inappropriate selection are of concern. Further study is required to eliminate this task. Could the force required be coded into the design of the wheelchair interface by a variation of the diameter or height of the engagement rods or by some other means?

The control panel is to be equipped with a light which will go on or off when the system pressure has been attained indicating that the hooks have properly been engaged. Perhaps the safest strategy would be to cause a warning light and a buzzer to operate during the interval that the securement system is between its fully retracted and fully engaged states. This would also provide warning of moving parts and of trip hazards whilst minimizing the "on" time of the signal and providing confirmation of both retraction and proper engagement.

Hazards to the User:

As the hooks travel toward the engagement points, they are prominent from the floor and there is a possibility that they may catch footrests, clothing, or more seriously, feet. The hooks exert a dragging force of approximately 42 lbsf, which is probably low enough to avoid significant injury. However, the 125 lbsf hold-down force capability is clearly more than sufficient to cause severe injury. The main danger would be with insensitive feet being drawn into the mechanism without the user's knowledge.

Effect of the System on the Function of the Wheelchair:

Use of this restraining system requires that wheelchairs either be designed to incorporate appropriate horizontal rods or else be made available with conversion kits. The wheelchair industry has undergone a major revolution in recent years with a shift toward customer preference for lightweight wheelchairs. The weight of manual chairs has been reduced from approximately 50 pounds to less than 30 pounds and users have demonstrated a willingness to pay $1000 or more for this 20 pound weight saving. It seems very unlikely that consumers would be prepared to add a restraining interface that would weigh between 15 and 20 pounds. This would be a significant impediment to daily function that would need to be carried throughout the day for the sake of shorter periods of time in vehicles. TES has estimated that conversions weighing between 5 and 10 pounds could be made available using lighter alloys at a higher cost. They have also suggested that the shock-absorbing ability of this wheelchair restraining system may enable the weight to be further reduced since the g forces applied to the restraining bar would be less. The suitability and acceptance of the system will depend, in my opinion, more on this factor than any other.

The presence of the horizontal restraining bar will present two other ergonomic issues for the wheelchair user, namely a limitation in ground clearance and a negative impact on the aesthetics of the chair.

Suitability of the System to Users with Different Disabilities:

This wheelchair restraint system is likely to be viewed very positively by users of powered chairs. It has the advantage of being able to be operated independently by a wider range of users since the system is automated. Even users with very limited upper limb function would be able to use the system if the control box is appropriately placed. In fact, the system could be readily adapted for use by any disabled person capable of operating a powered wheelchair by any means. The limitation on independent use might be the need to attach the personal safety belt (an issue that has not been addressed in this study). It is likely that the powered chair user will feel a sense of security because of the very firm and positive restraining action of this system.

It is anticipated that users of manually powered wheelchairs will have much less favourable responses to this restraint system. Many of these individuals have invested significant sums of money in acquiring lightweight wheelchairs to provide them with maximum performance. They would be likely to resent increases in weight and decreases in ground clearance that would result from the modification of the chairs to interface with this restraint. Clearly, this aspect of the wheelchair restraint requires more study. Some users might find an ultra lightweight design that does not inhibit the folding of the chair to be acceptable, but others may require a design that would make the restraining bars easily removable from the wheelchair. Such a system might be envisaged, perhaps using a special reaching aid so that the user is able to install and remove the bars.

The Operator:

The operator will be concerned with the ease of use of the system since he will be required to provide assistance on many occasion. In this respect, the wheelchair restraint system appears to be very simple to operate and its function relatively easily understood. The operator will be anxious to be reassured that the securement has been properly achieved. In the case of manual wheelchairs, it should be relatively easy to visualize the system from the normal pushing position behind the chair. However, with electric chairs there are many obstructions that may make it difficult to actually see whether the hooks have properly engaged with the rods and it will be necessary to rely on the hydraulic pressure indicating light. It has not been possible to test a range of powered chairs as part of this ergonomic study, but it would be necessary to check that a false indication could not be provided if the hooks interfered with some other component of the chair that would provide sufficient resistance to their motion but would not provide appropriate securement.

Presumably, the slots in the floor will always be covered by sliding or hinged doors that close automatically when the hooks are retracted. There would be obvious

tripping hazards for operators if the system is permitted to remain in a semi-retracted position with the doors open. Such a situation might be envisaged if the system is operated by a hand pump and operators find that it is a useful time saver only to disengage the hooks sufficiently to enable the chair to pass over without ensuring that they are properly folded under the floor with the doors in place.

Operators are likely to perceive a significant liability with the present design because of opportunities for injuring users' feet that may become entrapped by the powered hooks. Significant effort must be directed at removing this hazard and overcoming this perception.

APPENDIX "D"

Economic Impact of a Standard Wheelchair Interface,
SYPHER:MUELLER International Inc., January 1989

ECONOMIC IMPACT OF A STANDARD WHEELCHAIR-VEHICLE INTERFACE

Prepared for
TES Limited, Ottawa

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January 1989

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I INTRODUCTION

In July, 1988, TES Limited received a contract from the Transportation Development Centre to develop a standard interface for securing wheelchairs in accessible transportation vehicles. As part of that contract, Sypher:Mueller International, Inc. (SMI) was retained to quantify the costs associated with utilizing the standard interface concept. SMI also agreed to review existing cost subsidy programs which may help to reduce the fiscal burden on the wheelchair user, and assess the potential productivity improvements in paratransit systems brought about by implementing a standard interface concept.

The objective of the TES project is to develop a standard wheelchair-vehicle interface applicable to all transportation modes and to all wheelchair configurations. During the July 28, 1988, project initiation meeting, the Transportation Development Centre agreed to limit the study to surface transportation modes only (i.e., buses, vans, trains, and personal vehicles). Aircraft and marine vessels were not to be included. This restriction was extended further on November 24, 1988, by TES who instructed SMI to only consider the economic impact of the standardized securement device on buses and vans.

SMI divided the economic impact analysis into four stages: the wheelchair; the vehicle; transportation efficiencies; and assistance programs. In the "wheelchair" assessments, SMI determined the approximate base price of existing wheelchairs, the costs for retrofitting the standard interface, and the potential market for retrofitted devices. The number of new wheelchairs purchased each year was then considered, and the annual incremental costs calculated.

A similar approach was taken to determine the economic impact a standard interface would have on existing and new vehicles, however, only the vehicles used in paratransit service were considered. Because data was not available, the study was not able to assess the number of vehicles in private hands or in service clubs equipped for transporting disabled individuals.

The net transportation efficiencies were calculated based on existing and projected paratransit services and the potential ridership increases directly attributable to the standardized wheelchair vehicle interface.

Finally, SMI summarized the current subsidy programs available to individual wheelchair purchasers, vehicle purchasers, and paratransit operators; and indicated where the expected costs and benefits may be realized. The costs and benefits of this economic assessment are summarized in the final chapter.

The reader should clearly understand that this economic impact study is an analysis of the standard interface concept, not an analysis of the prototype developed by TES to demonstrate the concept. To clarify this point, TES has provided equipment costs and operational characteristics that, in their opinion, accurately reflect the expected costs of a securement device which meets the standard interface concept. Those estimated costs and operational characteristics may not necessarily reflect the true costs and characteristics of the TES prototype.

It should also be clear that this economic analysis is based on the premiss of universal implementation. Transitional costs, that is those costs associated with operating a vehicle with multiple securement systems so as to accommodate both standardized and non-standardized wheelchairs, have not been included. However, the transportation services offered to the disabled are so closely linked with specific clients that a viable implementation plan could be developed by each service so as to minimize or eliminate transitional costs.

II WHEELCHAIR OWNERSHIP COSTS

A WHEELCHAIR CLASSIFICATION

As described in TES's "Development of a Wheelchair Securement System, Interim Report I", wheelchairs can be described by one of five generic descriptions:

1. Standard manual
2. Standard electric
3. 3 wheeled chairs
4. 4 wheeled chairs
5. Other

"The first two generic types are normally classified as conventional wheelchairs and are characterized by their standard configuration as shown in Figure 1A. A standard manual wheelchair is propelled through the hand-rim by the user as depicted in Figure 2 whereas a standard electric wheelchair is electrically powered by a battery as shown in Figure 3.

"The last three generic types of wheelchairs are classified as non-conventional and are wheelchairs that possess innovative or special features that differ from the standard conventional wheelchair. These non-conventional wheelchairs are normally electrically powered since the conventional large rear wheels used for manual operation are not provided. Figure 1B depicts an illustration of a typical non-conventional wheelchair. The "Other" classifications refers to wheelchairs which do not suit any of the former classifications. Typical examples are the joy (Ortho-Kinetics Inc.) and the Transporter (Safety Travel Chairs Inc.) models for children which appear in Appendix "B".

B WHEELCHAIR COSTS

In Table 1 of the Interim Report, numerous commercially available wheelchair models are listed for each classification.

FIGURE 1
WHEELCHAIR CLASSIFICATION
REPRINT

A

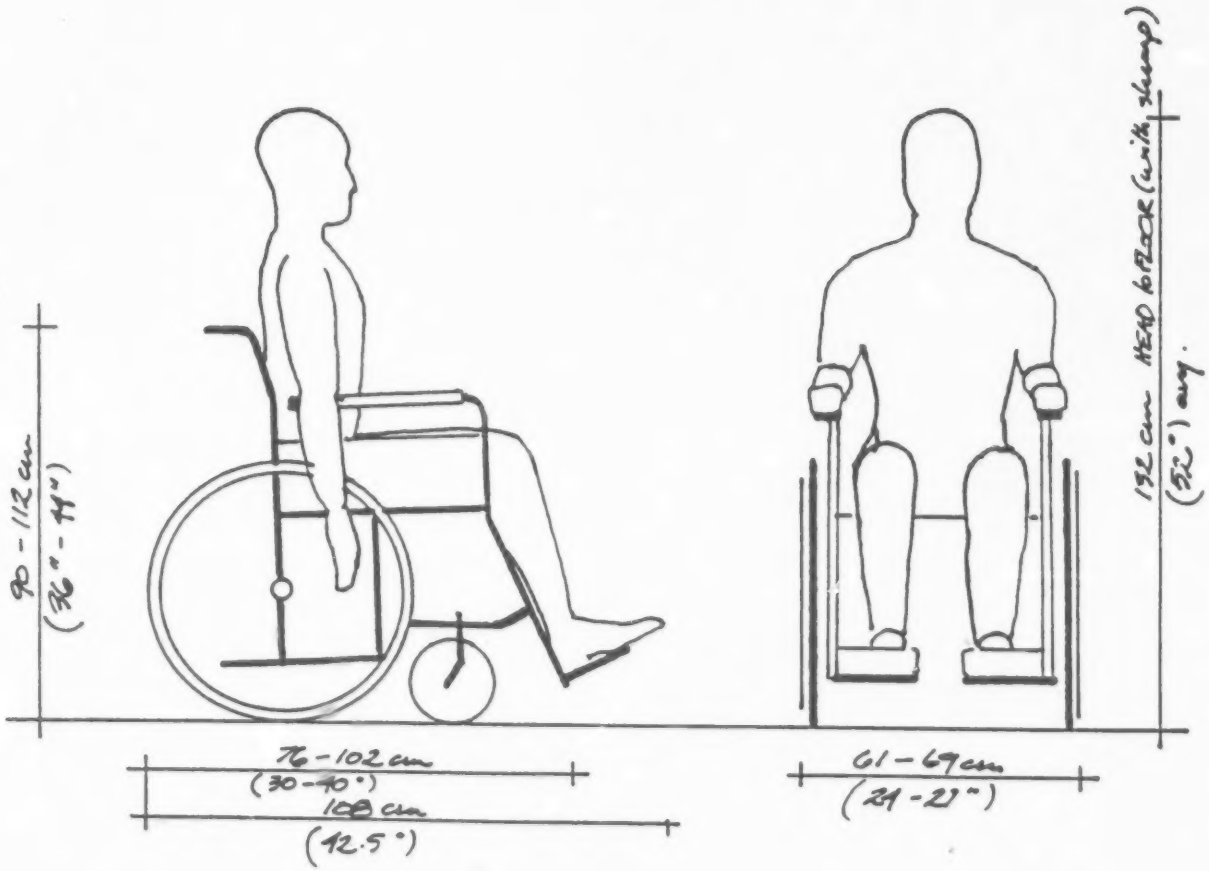
Conventional Wheelchair

B

Non-Conventional Wheelchair

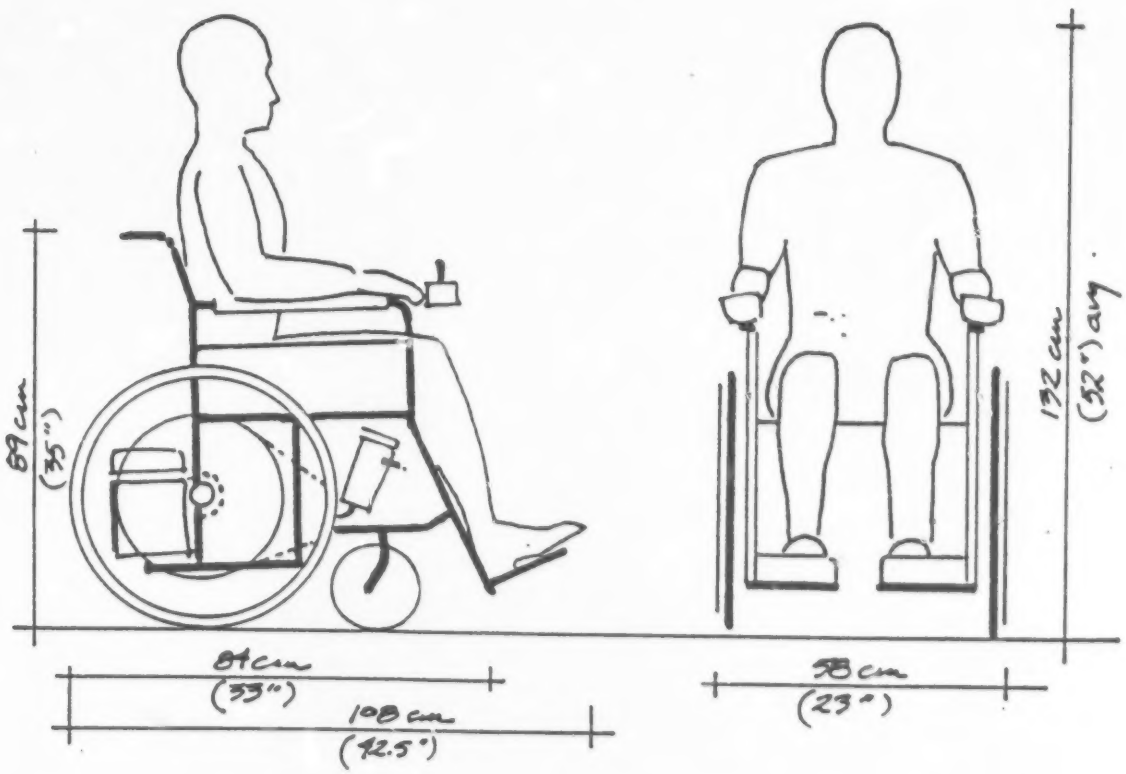
Source: "Development of a Wheelchair Securement System, Interim Report I", (TES Limited, Ottawa, February 1987), p. 3.

FIGURE 2
STANDARD MANUAL WHEELCHAIR
REPRINT



Source: "Development of a Wheelchair Securement System, Interim Report 1 "(TES Limited, Ottawa, February 1987), p. 4.

FIGURE 3
STANDARD ELECTRIC WHEELCHAIR
REPRINT



Source: "Development of Wheelchair Securement System, Interim Report I" (TES Limited, Ottawa, February 1987), p. 5.

To determine the financial impact on the wheelchair owner, SMI contacted a number of wheelchair suppliers in the Ottawa area and obtained the retail price for a sample of randomly selected wheelchairs. Table 1 provides a summary of the information received.

TABLE 1
OTTAWA RETAIL PRICE OF WHEELCHAIRS

MANUFACTURE	MODEL	TYPE	RETAIL PRICE	COMMENTS
Fortress Scientific	2000 FS	3	$ 3,040	Batteries Extra
Ortho Kinetics	Sierra	3	$ 2,694	Batteries Extra
	Bravo	3	$ 2,156	Batteries Extra
	Pony	3	$ 2,282	Batteries Extra
Everest & Jennings	Premier	1	$ 1,055	
	Starliner	1	$ 573	
	Ultralight Premier	1	2,360	includes armrests@ $126 and footrests @ $210
Invacar	Dart	3	$ 2,889	Batteries Extra
Motion Designs	Quickie II	1	$ 2,320	
	Quickie III	1	$ 1,780	
	RX	1	$ 1,340	

These prices reflect the asking retail price for wheelchairs suitable for male adults weighing 75kg. Footrests and arm rests are included in all cases, if available.

Modifications to existing and new wheelchairs will be required in order to make them comply with the standardized interface. The estimated prices for these modifications where supplied by TES.

C RETROFIT COSTS FOR EXISTING WHEELCHAIRS

The cost of the adapter kits, as illustrated in Table 2, reflect non-recurring retail costs (i.e. exclusive of engineering and design, inclusive of materials, manufacturing, packaging, distribution, markup, and profit). The costs are based on minimum production volumes of not less than one thousand for each kit offered.

TES estimates that at least two different kits will be required, one for conventional folding wheelchairs, a second for non-folding chairs and scooters. The adapter kit developed for folding wheelchairs will likely be the more expensive of the kits due to the incorporation of a hinge within the structural components.

D INCREMENTAL COSTS FOR NEW WHEELCHAIRS

The incremental costs, also illustrated in Table 2, are based on a wheelchair securement interface which is completely integrated into the overall wheelchair design by the wheelchair manufacturer, and reflects the anticipated incremental retail costs.

Table 3 illustrates the potential total capital costs for adapter kits fitted to existing wheelchairs, and the incremental retail price for new wheelchairs.

TABLE 2
RETROFIT AND INCREMENTAL COSTS FOR EQUIPPING WHEELCHAIRS WITH A STANDARD INTERFACE

RETROFIT COSTS			INCREMENTAL COSTS
MATERIAL	LABOUR	TOTAL	
$100 to $200	$100 to $150	$200 to $350	$50 to $200

TABLE 3
FINANCIAL IMPACT OF STANDARD INTERFACE MECHANISM ON NEW AND EXISTING WHEELCHAIRS

	STANDARD MANUAL WHEELCHAIR (TYPE 1)	THREE WHEELED CHAIR (TYPE 3)
Retrofitted Interface *		
Wheelchair Purchase Price	$573 to $2360	$2156 to $3040
Adapter List Price	$100 to $ 200	$ 100 to $ 200
Labour Cost to Install Adapter Kit	$100 to $ 150	$ 100 to $ 150
Total Capital Cost for Wheelchair with Retrofitted Adapter	$773 to $2710	$2356 to $3390
Percentage Increase in Price over Purchase Price	+8.5% to 61.1%	+6.6% to 16.2%
OEM Installed Interface		
Incremental Cost Increase for OEM Wheelchair Interface	$ 50 to $ 200	$ 50 to $ 200
Percentage Increase in OEM Price	+2.1% to +34.9%	+1.6% to 9.3%

* Based on data contained in Table 1

E INDIVIDUAL COSTS

Table 3 illustrates that the greatest hardship will be imposed on those persons who own or purchase the least expensive wheelchair. In practice, this disproportionate financial burden places the highest cost on that segment of the wheelchair users who can least afford incremental costs of $50 to $350.

> "Because most disabled person are not employed, they have lower than average incomes. A comparison of income levels between those reporting a disability and the Canadian population in general indicates that 30.6% of income recipients in the total population have incomes of $20,000 or more, compared to 14.5% of those with a disability.
>
> "The income level for disabled person tends to decline as the severity of the disability rises, so that only 3.5% of persons reporting a major disability have incomes of $20,000 or more.
>
> "People with the most severe degrees of disability are least likely to earn income, and are also more likely to incur additional expenses as a result of their disabilities.[2]

F NATIONAL COSTS

The Canadian Profile of Transportation and Disabled Persons Report concluded that 75,000 Canadians relied on a wheelchair for mobility.[3] However, of the 142,000 Canadians who needed special transportation services, only 80,000 have access to it, and only 42,000 use such services.[4] The CUTA survey indicated that 36% of their clients rode in wheel chairs. Thus, using the 36% figure on the 42,000 Canadians who use the paratransit system, 15,120 wheelchairs will need modifications.

The CUTA 36% figure of clients riding in wheelchairs is slightly different than the figure obtained by TES in their survey of 23 paratransit fleet operators. The TES survey indicated that 41% of their clients rode in wheelchairs.[5] Using the 41% figure on the 42,000 Canadians who use the paratransit systems indicates 17,220 existing wheelchairs will need modification. For the purposes of this economic impact analysis, SMI have chosen the TES 41% figure to reflect the number of wheelchairs needing modification. In doing so, the national costs may be somewhat overstated.

At a cost of $200 to $350 per wheelchair, the national costs will be $3.4 to $6.0 million. The TES survey also showed a growth in ridership of 13% over the last year. If this growth continues, the incremental increase of wheelchair purchases will be $112,000 to $448,000 per year, nationally. No figure was obtained for the life of a wheelchair, hence no cost has been determined for replacement wheelchairs.

III VEHICLE OWNERSHIP COSTS

A VEHICLE CLASSIFICATION

As described in the Introduction, this economic impact analysis of the standard interface concept only considers the highway transport mode. Within the highway mode, vehicle configurations include passenger cars, vans, and buses.

The distinction between vehicle classifications is based principally on the definitions contained in the Canada Motor Vehicle Safety Standards (CMVSS). A passenger car is essential defined as a self-propelled vehicle designed for ten occupants or less. A "van" refers to a multi-purpose passenger vehicle which is also designed for ten occupants or less but is built on a truck chassis or has special features for off-highway use. A bus is designed for more than ten occupants. In all cases, the number of occupants includes the vehicle operator (i.e. the driver).

(i) Passenger Cars

Without major modifications, passenger cars are not suitable for transporting disabled persons while they are seated in wheelchairs. According to a survey of one hundred and fifty 1984 and 1985 passenger cars, the floor to ceiling height of passenger cars varies from 857 mm to 1129 mm, whereas an adult wheelchair occupant needs 1320 mm of headroom. While this problem may be solved by installing a raised roof, a more serious limitation is imposed by the position of the drivers eye height (assuming a mobility impaired driver operates the vehicle while seated in a wheelchair) in relation to the windshield and side windows, mirrors, controls, etc.

A number of passenger cars have been modified with a raised roof section for mobility impaired passengers, most notably the "Camel Cabs" operated in Vancouver. Two other concepts which have been considered are the GSM Taxi Design Concept, and the introduction of a North American version of the London Taxi. This economic study was unable to obtain a suggested retail price for any of these passenger car designs.

(ii) Vans

The interior proportions of vans are typically an improvement over passenger cars, although some vans have interior floor to ceiling clearance of only 1015 mm. Even with a maximum floor to ceiling height of 1384 mm, virtually all vans must be modified to accommodate disabled persons seated in wheelchairs and wheelchair seated drivers. Typical van modifications include a wheelchair lift, enlarged doors, and either a raised roof or a lowered floor - sometimes both. Van conversions can, and frequently do, involve the replacement of the van body with a wider unit. These body replacements come in two nominal widths, 2300 mm and 2500 mm.

Vans operated by disabled persons are typically ordered with specific factory installed options, such as power windows and door locks, cruise control, special outside mirrors, automatic transmission, power steering and brakes, heavy duty battery and alternator, tilting steering wheel and heavy duty suspension. These factory installed options help compensate for the operators disability, and raise the price of the "basic" vehicle, prior to modification.

(iii) Buses

In addition to the standard transit (eg. GM's Classic), intercity (eg. Prevost's Mirage) and custom buses (eg. OBI's ORION II), some vans have sufficient seating capacity to be considered buses. These vehicles are rarely purchased as a private vehicle, but are the mainstay of the paratransit fleets. Except for the van conversions, buses do not typically require body modifications other than those needed to incorporate a wheel chair lift and wheelchair securement mechanism(s).

B VEHICLE COSTS & OWNERSHIP

Table 4 summarizes typical prices for vehicles in each vehicle classification.

To determine who currently owns vehicles equipped to transport disabled persons in wheelchairs, SMI identified five classifications:

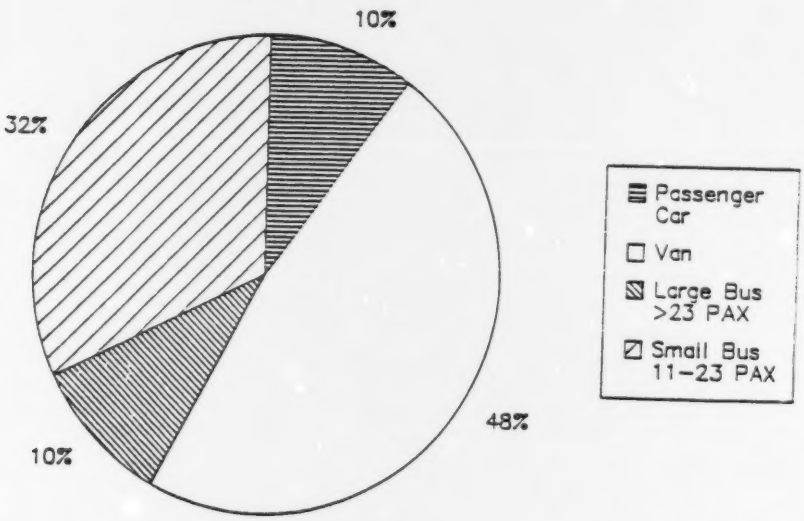
(i) Personal Transportation or Transportation of Family Members.

Some jurisdictions issue special licence plates for use on private and/or commercial vehicles used to transport disabled persons, or allow distinctive "disabled" signs to be displayed on such vehicles. These licence plates and signs allow, amongst other benefits, access to parking spaces specifically reserved for the disabled. Not all jurisdictions keep records of the number of special licence plates or "disabled" signs issued to private vehicles, nor are they typically able to determine if the vehicle authorized to display the distinctive licenses/signs are equipped with a wheelchair securement device.

(ii) Paratransit Services.

This term generally refers to all public transportation services designed specifically for the needs of the disabled. Although not every paratransit fleet operates a "many to many" system, most do. Through the Canadian Urban Transit Association (CUTA), SMI obtained a summary of a survey answered by 106 paratransit fleet operators. Based on those 106 responses, the make-up of the paratransit fleet is represented in Figure 4.

FIGURE 4
VEHICLE MIX WITHIN 1986 PARATRANSIT FLEET



Source: Transit Services for the Disabled in Canada: 1986 Data (Canadian Urban Transit Association, Toronto), p. 15.

(iii) Service Clubs.

SMI estimate that there is a significant fleet of vehicles equipped to transport physically disabled persons operated by service clubs, such as the Lions Society, the Shriner's, the Crippled Children's Society, etc., Vehicles purchased by these clubs may either be donated to deserving agencies, such as a children's hospital or retirement home, or operated by the club for a number of different benefactors. No conclusive data was obtained, but SMI suggests that most of these service club vehicles could operate a "many to one/one to many" or a "line haul" type service.

No count of the number of such vehicles currently in use was obtained, but SMI suggests most of these vehicles will be either vans or small buses.

(iv) Institutions.

Many hospitals, rehabilitation centres, nursing homes, and retirement homes operate their own vans or small buses for the purpose of transporting their patients. An unknown portion of these vehicles will be equipped with wheelchairs securement devices. As with service clubs, SMI suggest most of the institutional services would provide a "many to one/one to many" or "line/haul" type service.

(v) School Buses.

School bus fleets are typically privately owned, but there are a number of publicly held systems in Canada. Due to the nature of school bus routing, most operators endeavor to integrate the transportation of physically disabled students within their "normal" operations, thus eliminating parallel service. The exception to this rule is where sufficient disabled student densities exist to warrant a dedicated service. Thus many school buses designed for regular service are equipped with a wheelchair lift and one or two wheelchair securement devices. While national figures were not obtained, SMI determined that 54 of British Columbia's 3113 permitted School Buses are equipped to transport wheelchairs.

Due to the lack of reliable data, SMI have concentrated on the cost/benefits to paratransit operations. Parallel costs and benefits would be realized by service clubs, institutions, and school bus fleets, but because vehicle utilization, labour rates, capacity, and demand will vary, no reliable estimate of the magnitude of those costs and benefits can be offered. As a consequence, both the net costs and the net benefits associated with introducing a standardize wheelchair vehicle interface will be understated in this report.

TABLE 4
SUMMARY OF TYPICAL VEHICLE PRICES

VEHICLE	USE	TYPICAL NUMBER OF WHEELCHAIR POSITIONS	TYPICAL COSTS
Passenger Car	Commerical/ Public (Taxi or Paratransit)	1 or 2	
Van (10 Occupants for less)			
Minivan	Private	1 or 2	$27,000 to $33,000
75" Width (Standard)	Private	1 or 2	$28,000 to $34,000
75" Width (Standard)	Commerical/Public	1 to 6	$40,000 to $45,000
90" Width (Cutaway)	Commerical/Public	1 to 5	$35,000 to $45,000
100" Width (Transit)	Commercial/Public	1 to 5	$40,000 to $45,000
Bus (More Tahn 10 Occupants)			
Van Conversion	Commercial/Public	1 to 4	$35,000 to $45,000
Body on Chassis	Commerical/Public	1 to 8	to $45,000
Custom	Commercial/Public	1 to 8	$150,000
Transit	Commerical/Public	1 or 2	$185,000
Intercity	Commercial/Public	1 or 2	$300,000 to $350,000

C RETROFIT COSTS FOR EXISTING VEHICLES

Adopting the standard interface into existing vehicles will require removal of the existing systems and installation of standardized interface. TES have estimated this cost to be $2,000 per position, including all labour and materials. The existing systems removed from the vehicle are considered scrap, with no value.

Based on the CUTA survey,[6] there are an estimated 526 vehicles carrying 3.5 million passengers in the paratransit system. The CUTA survey did not identify the number of wheelchair positions per vehicle or per fleet, therefore SMI have had to make an estimate of the number of such positions. Based on the fact that 48% of the surveyed paratransit fleet are vans (with a maximum wheelchair capacity of four) and that 32% of the surveyed fleet are small buses (with one to eight wheelchair positions), SMI estimates an average of 2.5 positions per vehicle. Based on this estimate, the total cost for standardizing the existing paratransit fleet would be $2.6 million. This translates to 75 cents per passenger if amortized over one year.

D INCREMENTAL COSTS FOR NEW VEHICLES

To determine the incremental cost for new vehicles, the capital and installation costs of existing securement systems were deducted from the standardized interface as proposed by TES. The cost of typical passenger wheelchair securement systems have been tabulated by TES in Table 7 of their Interim Report # 1, a copy of which is reproduced here as Table 5.

TABLE 5
SUMMARY OF COMMERCIALLY AVAILABLE WHEELCHAIR SECUREMENT SYSTEMS
REPRINT

	Manufacturer or Distributor	Attachment to: Vehicle: Floor	Vehicle: Wall	Vehicle: Rim	Vehicle: Tire	Wheelchair: Forward Post	Wheelchair: Caster Arch	Wheelchair: Bottom Rail	Wheelchair: Cross Brace	Wheelchair: Back Post	Cost	Belt: L	Belt: S
A	ABC Enterprises		X	X									
	ANF	X				X				X			
	Aerospace Corporation	X				X			X				
	Aerospace Corporation	X				X				X			
	Aerospace Corporation	X				X				X			
	Brown Corporation	X				X				X	$125US		
	Handicaps Inc.	X											
	Rootes Maidstone Ltd.	X					X						
	Girardin G-straint	X				X				X	$375CDN	Y	Y
	Metallic Component	X				X				X			
	Crow River	X				X	X			X	$119US		
	Crow River	X				X	X				$119US		
	Wacs		X							X		Y	Y
B	ABC Enterprises	X						X					
	Ferno Washington Inc.	X							X		$140CDN		
	Mobility Dynamics Inc.	X						X					
	Para Industries (1978) Ltd.	X						X					
	Para Industries (1978) Ltd.	X						X					
	Fred Scott & Sons	X						X					
	Skillcraft Industries Inc.	X						X					
C	Coach & Car	X					X				$43US		
	Drive Master Corp. (1981)	X									$40US		
	Braun Corporation	X					X				$140US		
	Oscar Instruments Co.	X						X					
	R.J. Mobility Systems	X							X				
	Rootes Maidstone Ltd.	X						X			$120US	Y	Y
	C.M. Unwin Ltd.	X						X					
	Greshaw	X					X				$100US		
	Greshaw	X								X	$100US		
D	ABC Enterprises	X	X	X									
	American Seating Co.			X									
	Atlantic Research Corp.	X		X									
	Atlantic Research Corp.	X		X									
	Braun Corporation	X		X									
	Collins Industries Ltd.	X		X							$150US	Y	Y
	Drive Master Corp. (1981)	X		X							$185US		
	Handi-Ramp Inc.	X	X	X							$55US		
	Transi-Lift Equipment		X	X									
	Coach and Car		X	X	X						$105US		
E	Braun Corporation	X				X					$144US		
	Braun Corporation	X									$140US		
	Drive Master Corp. (1981)	X				X			X		$185US		
	Caltrans Brobeck Corp.	X										Y	
F	Creative Controls	X											
	Falcon	X							X			Y	
	Reb	X		X	X								
	Auto Service	X		X		X							
	Sask. Crippled Children	X							X				
	TDC	X	X		X							Y	Y
	TDC	X	X		X							Y	Y
	Hendersons											Y	Y

NOTE: Source Ref. 4

A - Belts
B - T-bars
C - Rod and Hook
D - Wheel or Rim Locks
E - Floor Mounted Locking
F - Other Devices
L - Lap
S - Shoulder

Source: "Development of a Wheelchair Securement System, Interim Report I", TES Report C839-1 (TES Limited, Ottawa, 1987), p. 28.

In addition to the systems described in Table 5, vehicles converted so as to be operated by a disabled person while sitting in a wheelchair may incorporate a "power pan" valued at $1,550, installed.

TES have considered these factors and estimated the total incremental OEM installed price to be $1,000 per wheelchair position.

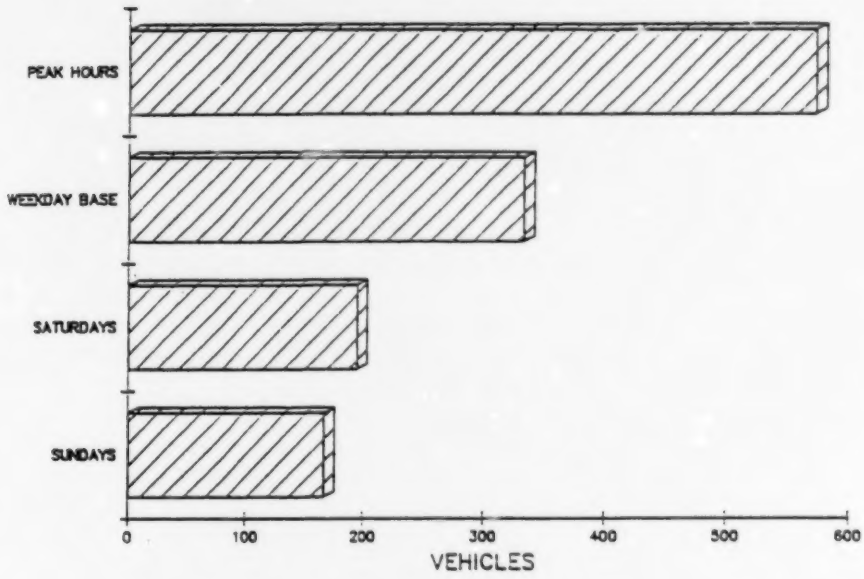
The average paratransit vehicle life span was suggested by a major Ottawa fleet operator to be seven years. Based on this life span, the 526 vehicles currently in the paratransit systems and 13% growth, an estimated 75 paratransit vehicles will be replaced and 69 new vehicles will be purchased nationally in the first year at an estimated incremental cost of $0.36 million for the wheelchair-vehicle interface.

IV BENEFITS/SAVINGS

A standardized wheelchair-vehicle interface suggests paratransit services will improve by reducing the time required to secure a wheelchair. Through laboratory evaluations of the TES prototype and field measurements of a "Q-straint" system, TES have concluded the prototype design will require 1.5 minutes to position and secure the wheelchair, whereas a Q-straint style system will require 3 to 5 minutes to actuate. A similar time period is required to remove the restraint and extricate the wheelchair. Thus the use of a standardize wheelchair-vehicle interface concept should save 3-7 minutes per wheelchair passenger trip.

In their Interim Report #2, TES surveyed paratransit operators and found 23 operators collectively operated 387 vehicles, transporting 38202 persons per week of whom 41% were transported in wheelchairs.[7] This translates to an average of less than 6 wheelchair passengers per day per vehicle. Data provided by CUTA is supportive of the TES data, but does not match exactly.[8] For example, CUTA data indicates 36% of passengers are transported while seated in wheelchairs. Using the CUTA data for the number of vehicles (526) and the number of passengers (3.5 million), this also translates to an average of 6 wheelchair passengers per vehicle per day. Thus the total time saved per vehicle per day is 18 to 42 minutes. However, the effect of this 18 to 42 minutes in highly dependent on the vehicle's utilization. To assess the impact of this efficiency savings, SMI looked at three different scenario's.

FIGURE 6
OPERATIONAL USE OF PARATRANSIT VEHICLES



Source: Transit Services for the Disabled in Canada: 1986 Data, (Canadian Urban Transit Association, Toronto), p. 13.

A SCENARIO I: CAPACITY EXCEEDS DEMAND

Based on both the TES and CUTA surveys, 14 to 17 passengers are carried per vehicle per day. If these 14 to 17 passengers are uniformly transported throughout the day, and the "day" is sufficiently long, then it is possible that the 3 to 7 minutes saved per passenger per day will have no significant effect on ridership.

This an example of vehicle capacity exceeding the demand for service. This would be an unusual situation indicating the fleet is currently not operating efficiently, but such a scenario may be necessary in very small, one to two vehicle, operations. This scenario also suggests the vehicles are currently transporting fewer passengers than the national average. Thus further system efficiencies would likely have no direct effect on either fleet size or ridership levels. The 3 to 7 minute savings would, however, allow the vehicle operator to improve level of service given each wheelchair passenger by reducing the total trip time.

B SCENARIO II: CAPACITY MEETS DEMAND

Figure 6, "Operational Use of Paratransit Vehicles" illustrates the national average deployment of vehicles to meet the peak demand hours. However, for paratransit systems, "peak hour demand" has considerable variance.

Using Ottawa's paratransit system as an example, 48 to 63 vehicles are in service during the peak hours of 7:00 A.M. to 6:00 P.M. While Ridership is high throughout the day, the peak demand occurs mid afternoon. Shortly after 6:00 P.M., demand drops to a point where 10 vehicles can accommodate all travel requests. Night service ceases at midnight. Weekend requests in Ottawa are met by 15 to 25 vehicles. Note that the Ottawa paratransit system does not fit the national average illustrated in Figure 6 where the number of vehicles needed to meet the peak hour demand can be reduced by 42% to meet the weekday base, by 66% for Saturday service, and by 71% for Sunday service.

Ottawa's paratransit system is able to meet existing demand with their existing (and recently expanded) fleet, making pick-ups within 1/2 hour of the requested time, and delivering the customer to their destination with 1 hour of the requested pick-up time (ie. a customer can meet his appointments by scheduling pick-up at least 1 hour prior to the appointment).

FIGURE 7
ESTIMATED OTTAWA
PARATRANSIT VEHICLE UTILIZATION

UTILIZATION	FUNCTION
13.0 hrs.	. Not in service
0.0 hrs.	. In service-waiting - no passengers
0.6 hrs.	. Travel to passengers (empty)
	. Prepare vehicle for embarking (includes possible relocation of existing passengers)
0.6 hrs.	. Prepare passenger for embarking (curb, door, or accessible door type service)
0.6 hrs.	. Embark vehicle
0.1 hrs. to 0.4 hrs.	. Access securement area and
	. Secure wheelchair
0.4 hrs.	. Secure occupant
0.1 hrs.	. Prepare vehicle for travel
7.2 hrs.	. Travel time (with passenger(s))
0.1 hrs. to 0.4 hrs.	. Prepare vehicle for disembarkation
	. Prepare passenger for disembarkation (includes possible relocation of existing passenger)
0.3 hrs.	. Disembark passenger (to curb, door, or accessible door location)
0.3 hrs.	. Prepare vehicle for travel
24.0 hrs.	

To quantify the potential benefits to paratransit systems by introducing a standardize wheelchair-vehicle interface, vehicle utilization was considered. Figure 7, Estimated Ottawa Paratransit Vehicle Utilization, was prepared to illustrate the utilization of an Ottawa paratransit vehicle assigned to peak hour service. All times provided in Figure 7 are estimates made by SMI based on the CUTA survey and an interview with the Ottawa paratransit fleet manager. An in-use survey of vehicle utilization was not conducted

From figure 7, those operational aspects which may be affected by a standardized wheelchair-vehicle interface consume approximately 2.8 hrs. (12% of total vehicle time or 25% of total "in-service" time). Therefore, the savings of 18 to 42 minutes (.3 to .7 hours) will have a measurable impact on the vehicle's efficiency. In the Ottawa Paratransit Fleet of 63 vehicles, a total of 18.9 to 44 hours could be saved (18 min X 63 vehicles - 42 min X 63 vehicles), which represents 1.7 to 4.0 vehicles per day. In other words, Ottawa Paratransit Services could provide the same level of service with 1 to 4 fewer vehicles if they could save 18 to 42 minutes per vehicle per day by utilizing a standardized interface. This represents a fleet improvement of 1.6 to 6.4 percent.

To further explore the impact a standardize wheelchair-vehicle interface would have on existing fleets, SMI contacted the Paratransit Fleet Manager in Vancouver.

Vancouver operates 170 vehicles to transport 1800 passengers per day. The percentage of these passengers transported while seated in wheelchairs is 30% or 5.3 wheelchair passengers per day per vehicle. This fraction of wheelchair passengers is less than the national average obtained by CUTA in their survey. The Vancouver paratransit system has two distinct peak hour periods, 7:00 to 9:00 A.M., and 3:00 to 5:00 P.M. The Fleet Manager indicated that the current fleet can meet the existing demand for service, however any system improvements would allow him to reduce his fleet size. Thus based on a 3 to 7 minute savings per wheelchair passenger, and 540 (30% of the 1800 daily passengers) are wheelchair bound, a total daily saving of 27 to 63 hours is conceivable. Based on an 8 hour utilization rate, this suggests 3 to 8 vehicles could be eliminated from the fleet. (A 2.0% to 4.6% reduction in fleet size.)

C SCENARIO III: DEMAND EXCEEDS CAPACITY

Based on the hypotheses that most passengers are transported during peak hours and demand exceeds supply, the 3 to 7 minutes saved in securing the wheelchair will directly impact ridership levels. The Winnipeg paratransit operation is one example fo such a system.

The Winnipeg "Handi Transit" fleet comprises of 19 vehicles plus an agreement with the Winnipeg Taxicab Board whereby wheelchair users can travel by taxi if they are able to move unassisted from the wheelchair to the taxi and if the wheelchair can fold for storage in the taxi trunk. In Winnipeg, the demand for service exceeds the capacity of the 19 vehicles "Handi Transit" fleet, thus the entire fleet is in service form 6:30 A.M. to 12:00 P.M. or 1:00 A.M. (less vehicles in the maintenance shop). Peak demand for service occurs between 6:30 A.M. and 10:00 A.M., and between 3:00 P.M. and 6:00 P.M.

D. SUMMARY OF BENEFITS AND SAVINGS

In the preceeding three scenarios, the introduction of a standardized wheelchair-vehicle interface will:

- where capacities exceeds demand, cause no reduction in fleet size or increase in ridership levels;
- where capacity meets demand, allow the fleet size to be reduced, thus allows savings in both operational expenses and capital budgets; and
- where demand exceeds capacity, allow the ridership levels to be increased within the current fleet size.

In the first scenario, the hypothesis lead to a 3 to 7 minute reduction in the trip time for each wheelchair passenger. Using the 1982 CUTA Paratransit Use Survey [9], the average number of passengers per hour is 2.58, or an average of 24 minutes per trip. Assuming this trip length holds true for systems where capacity exceeds demand, trip lengths may be reduced to an average between 17 and 21 minutes. Thus, while no direct economic benefits will result, the level of service given passengers will improve.

In the second scenario, the hypothesis lead to a fleet savings of 1.6 to 6.4 percent, in the Ottawa example; and 2.0 to 4.6 percent, in the Vancouver example. Assuming these savings would apply equally to both the annual operating and equipment budgets, the annual saving would be:

National Annual Operating Budget:[10]	45.9 m.
National Annual Equipment Budget:[11]	5.0 m.
Total National Paratransit Budget:	50.9 m.
Efficiency Savings (Ottawa)	1.6% to 6.4%
Efficiency Savings (Vancouver)	2.0% to 4.6%
National Annual Savings	
(1.6% of $50.9 m) =	$0.81 m.
(6.4% of $50.9 m) =	$3.26 m.
(2.0% of $50.9 m) =	$1.02 m.
(4.6% of $50.9 m) =	$2.34 m.

Thus the total savings in National Paratransit Budgets per year could be $0.81 m to $3.26 m if every paratransit fleet was operating at capacity.

In the final scenario, the hypothesis lead to an increase in ridership. Based on the CUTA average vehicle ridership per day data, the system efficiencies would be:

Number of passengers transported per year:	3.5 million
Number of vehicles in fleet:	526
Number of passengers per vehicle per week:	127.96/wk
Number wheelchair passengers per week per vehicle: (36% of 127.96/wk)	46.07/wk
Time saved per week per vehicle	
(46.07 passengers x 3 min) =	2.30hrs./wk
(46.07 passengers x 7 min) =	5.37hrs./wk
Average number of all passengers per vehicle per hour:	2.58/hr.
Increased passenger loud due to time saved	
(2.30 hrs.x 2.58 passengers hr) =	5.93/wk
(5.37 hrs.x 2.58 passengers hr) =	13.851/wk
Ridership improvements	
(5.93 divided by 46.07 x 100) =	12.87%
(13.85 divided by 46.07 x 100) =	30.06%
National Paratransit Budget:	$50.9 m
Cost per passenger ($50.9 m divided by 3.5 mil.passengers) =	$14.54/passenger

National Ridership levels due to efficiencies

(3.5 m x 112.87%) =	3.85 million
(3.5 m x 130.06%) =	4.55 million

Cost per passenger

($50.9 m divided by 3.85 million) =	$13.22/passenger
($50.9 m divided by 4.55 million) =	$11.99/passenger

Savings per passenger

($14.54 - $13.22) =	$1.32
($14.54 - $11.99) =	$2.55

Thus, in a demand exceeds capacity scenario, the standardized wheelchair-vehicle interface will:

- increase ridership levels 12.9 to 30.1%; and
- reduce ridership costs per passenger by $1.32 to $2.55.

For both Scenario II (Capacity Meets Demand) and Scenario III (Demand Exceeds Supply) an word of caution must be issued. Increased ridership per vehicle requires increased travel time for pick-up and drop-off. As a result the trip length for the existing passengers is lengthened, perhaps to a point where ride time will exceed service standards. The ridership levels are one of the reasons most large paratransit fleet operators operate many small vans rather then a fewer larger buses.

V FINANCIAL ASSISTANCE PROGRAMS

In their 1981 report to the House of Commons, the members of the Special Committee on the Disable and the Handicapped unanimously endorsed the principle that all Canadians are responsible for the necessary changes which will given disabled persons the choice of participation equivalent to that enjoyed by those who are not disabled.

Financial programs designed to assist disabled person vary from province to province, and are typically case specific. A program by program evaluation is beyond the scope of this economic impact analysis; however, within each province, the following programs typically exist.

Vocational Rehabilitation of Disabled Persons Program (VRDP).

- Jointly funded by the federal and provincial governments, administered by the provincial governments.
- Subsidizes the cost of purchasing adaptive aids needed for either education or employment purposes.
- Because subsidies are approved on a case by case basis, no firm commitment could be obtained respecting the purchase of a standardized wheelchair securement device, but numerous examples are available showing the program has contributed towards other wheelchair securement adaptive devices.

Vehicle Insurance Policies

- Provincial crown corporations offering automobile insurance and government regulated insurance companies frequently provide financial assistance to persons needing adaptive aids if the disability is a result of a vehicular accident.

Workers Compensation Board

- Most WCB programs meet all, or a substantial portion of rehabilitative financial needs of insured workers injured on the job.

Service Clubs

- These community service organizations typically offer short term, expedient, or stop gap assistance to a disabled persons unable to meet the financial burdens. While a means test is not typically administered, an assessment of the recipients ability to pay is frequently determined.

Government Agencies and Provincial Health Programs

- Numerous provincial agencies and health insurance policies offer financial protection or assistance to disabled persons. Most provincial welfare agencies administer a means test, and are considered a last resort. Health insurance programs typically provide basic coverage for the adaptive equipment designed to overcome a disability, but may not extend financial assistance to adaptive aids needed for transportation.

A detailed listing of these programs is contained in Transport Canada's "Vehicles and Adaptive Aids for Elderly and Disabled Drivers, A Buyer's Guide" (TP 6895). This listing is somewhat dated, but provides a good source list for financial assistance on a province by province basis.

A second source list for transportation assistance is contained in Table 4 of Interim Report #1, a copy of which is reproduced here as Table 6.

TABLE 6
SUMMARY OF TRANSPORTATION SERVICES
(REPRINT)

Province	Program & Administering Dept.	Eligibility Criteria	Delivery Mechanism	Funding by Province
Alberta (1985)	Alberta Transportation: - Special transportation services program for the elderly, the handicapped and the disabled.	Most systems are for "adults who would have difficulty using regular transit." Small communities may serve broader categories, all ages and handicaps.	Municipality is responsible for delivery. Several provider options including use of taxis.	75% of study costs. All rural and urban communities receive unconditional grants of $3.00 per capita. In small cities and large towns without conventional transit service an additional $3.00 per capita may be granted to fund a "paratransit" service.
British Columbia (1985)	BC Transit: - Handy DART or "Custom Transit". - "Paratransit" services for communities without conventional transit.	To assist persons who cannot use conventional services without assistance. Includes all ages, incomes, and mental handicaps.	In greater Vancouver and Victoria, BC Transit contracts directly with the operating companies; in smaller communities, the municipality is also a party to these agreements. Agreements stipulate annual hours of service and operating budgets. BC Transit monitors service and assists operators with planning and technical advice.	Farebox revenue is targeted at 10% of costs. A provincial supplement contributes 25% in greater Vancouver and Victoria and 20% in smaller communities. The deficit is shared between the province and municipality in accordance with a financing formula and agreement. In the fourth and subsequent years of custom transit operation, the province normally contributes 66.7% of the deficit. BC Transit leases most vehicles to operators, funds 50% of feasibility study costs, and provides technical support.
Manitoba (1985)	Urban Affairs: "Handi Transit" program. Dept. of Highways and Transportation for rural program.	By Municipality. Eligible users are the physically handicapped who cannot use public transit. 22 rural areas served.	Municipality provides vehicles. Province sets out initial expectations of service.	Municipal - 50%. Provincial - 50% for cities and 37.5% for rural areas. Rural funding limit of $10,000 for vehicles and $20,000 for operations.
New Brunswick (1985)	No specific legislation.	Funding and service policies are the responsibility of the local municipalities.	Major cities have service.	None. Funding from the federal Urban Transportation Assistance Program (UTAP) was used until 1983.
Newfoundland	Department of Transportation.	Those persons who have difficulty using conventional transit due to a disability.	St. John's only has an on-demand service operated by local service organization.	Provision and maintenance of vehicles. Provincial operating subsidies.
Nova Scotia (1985)	Department of Municipal Affairs. (Policy adopted in 1979).	All handicapped persons.	Municipal transit agency contracts for service.	Province provides: - 50% of capital costs. - Operating subsidy of $1.15 per capita in 1985.

TABLE 6 - Continued

Ontario (1979)	Ministry of Transportation & Communications. Transportation for the Physically Disabled.	Any municipality, regardless of whether they have existing public transit. Definition of user is physically disabled person who is unable to board regular transit facilities. No age, income limitation. Includes mentally handicapped who meet definition.	Municipality sets up systems and selects own operator. Province reviews contracts and proposals. Sets explicit service and safety standards, administrative procedures and monitoring.	Province provides: - 50% of capital costs. - Basic subsidy of 25% of eligible operating costs if province assisted in funding vehicles; 30% if province did not. - Further subsidy of $2.60 per trip. - Supplementary assistance if trip lengths exceed 9 km.
P.E.I.	No specific policy, Social Services subsidy in Charlottetown.	By municipality.	Charlottetown only has service.	None.
Quebec (1983)	Minister des transports. Subventions au transport des Personnes Handicapees.	Eligibility committee with municipal and user advocate representatives. Definition based on ability to use conventional transit with dignity.	Municipality is key. Some 400 municipalities are served by 55 systems.	Province provides: - 75% of capital costs. - 75% of operating costs.
Saskatchewan (1985)	Department of Urban Affairs: "Transit for the Disabled Program".	Municipalities define eligibility. Generally: "To assist all persons who cannot use conventional transit systems with dignity".	Municipality. Communities own vehicles and contract for service. Province sets out certain service conditions.	Province provides: - 75% of acquisition of specially equipped vehicles. - 50% of operating deficit. - 75% for studies and demonstration projects.
Yukon	Department of Health and Human Resources.	"Unable to use conventional transit" - includes physically and mentally handicapped.	Yukon Government has a contract with Whitehorse Transit only.	Yukon Government provides: - 60% capital. - 100% operating.

Source: Development of a Wheelchair Securement System, Interim Report 1, TES Report C839-1 (TES Limited, Ottawa, 1987), p. 16 & 17.

The CUTA 1986 data provides an insight into the financial subsidies offered the paratransit operators, and concludes the average cost per passenger (exceeding Pepreciation and Interest on Debt) is $13.02, of which:

- the passengers pay an average of $1.09;
- the municipality subsidizes $3.84;
- the provincial government subsidizes $7.05; and
- other sources subsidize $0.12.

No explanation is offered for the short fall of $0.92, but one explanation is that it may come from the regular transit operating budget. The average cost per passenger of $13.02 is based on operating costs, whereas the cost per passenger of $14.54 used in section D, chapter 4, is based on operating, capital, interest on debt costs.

Table 7 summarizes the transit operating costs and revenues.

TABLE 7
PARATRANSIT OPERATING COSTS & REVENUES

PROVINCE	OPERATING COST	OPERATING SUBSIDES		OTHER	ADULT CASH
	$	MUNICIPAL $	PROVINCIAL $	$	FARE $
British Columbia	2,471,603	353,339	1,672,149		1.08
Alberta	4,119,741	219,085	261,021	112,660	1.01
Saskatchewan	1,544,046	490,894	511,250	10,365	1.45
Manitoba	48,704	6,400	18,264		
Ontario	22,612,464	8,880,285	11,340,460	263,063	1.00
Quebec	14,506,631	3,487,001	10,739.344	45,496	1.03
New Brunswick	34,038	28,038		12,015	1.50
Nova Scotia	509,484	183,984	401,000		1.38
PEI					
Newfoundland					
Yukon	50,679		80,605		0.25
N.W.T.					
TOTAL	45,978,390	13,649,027 2	5,024,093	443,599	
AVERAGE					

VI SUMMARY & CONCLUSIONS

The principle conclusions of this economic impact study into a standardized wheelchair vehicle interface are:

- Individual wheelchair owners can expect a cost burden of $200 to $350 to retrofit the standard interface to existing wheelchairs, and an incremental cost $50 to $200 for each new wheelchair which incorporates the standard interface.

- The national costs for retrofitting interface devices to existing wheelchairs will be $3.4 to $6.0 million, and an incremental cost of $0.1 to 0.5 million/year for new wheelchairs.

- Retrofitting the interface to existing paratransit vehicles will cost approximately $5,000 per vehicle, or $2.6 million nationally. Assuming a one year payback, this translates to about 74 cents per passenger per trip.

- New vehicles equipped with the standard interface would cost about $2,500 more, with a national incremental cost for new paratransit vehicles being $0.36 million/year.

- The Vocational Rehabilitation of Disabled Persons Programs (VRDP) does contribute to adoptive aids needed for educational or employment purposes, including wheelchair securement systems. Should a standardized wheelchair-vehicle interface be adopted on a national basis, it is likely the VRDP would continue to contribute towards wheelchair securement devices provided they are used for educational or employment purposes.

- System efficiencies brought about by the faster wheelchair securement times possible with a standardized interface could amount to $0.81 to $3.26 million annually, or $0.73 to $1.82 per passenger trip. Savings of this magnitude are based on a paratransit system able to meet existing demand for services. Should service exceed existing demand, no savings will accrue.

Based on these conclusions, Table 8 was prepared to summarize the costs associated with implementing a standard wheelchair-vehicle interface and the allocation of the financial burden.

TABLE 8
SUMMARY OF STANDARDIZED INTERFACE COSTS & FINANCIAL BURDEN

ITEM	COST/BURDEN PER UNIT	INCREMENTAL NATIONAL COST (MILLION)	FREQUENCY	FINANCIAL BURDEN TO:
Retrofit Wheelchair	$200 to $350	$3.4 to $6.0	One Time	-Wheelchair Owner -Aid Programs (Federal and Provincial) -Welfare Programs -Insurance Companies (Vehicle & Health) -Workers Compensation Boar -Service Clubs
New Wheelchair	$50 to $200	$0.1 to $0.5	Annual	
Retrofit Vehicle	$5000	$2.6	One Time	-Federal, Provincial, & Municipal Transit Subsides. -Service Clubs -All Service Users
New Vehicle	$2500	$0.36	Annual	
Paratransit System Efficiency				-(Federal, Provincial, & Municipal Transit Subsides) -(Transit Operating Authorities) -(Private Paratransit Operators)
Capacity Exceeds Demand		nil	N/A	
Capacity Meets Demand		($0.81 to $3.26)	Annual	
Demand Exceeds Capacity		nil	N/A	

To illustrate the potential payback period for a paratransit fleet where the fleet capacity is equal to the demand for service, Figure 5 was prepared.

In Figure 5, the initial costs are calculated as:

minimum:	$3.4m	to retrofit wheelchair
	+ $2.6m	to retrofit paratransit fleet
	$6.0m	
maximum:	$6.0m	to retrofit wheelchair
	$2.6m	to retrofit paratransit fleet
	$8.6m	

The incremental costs are calculated as:

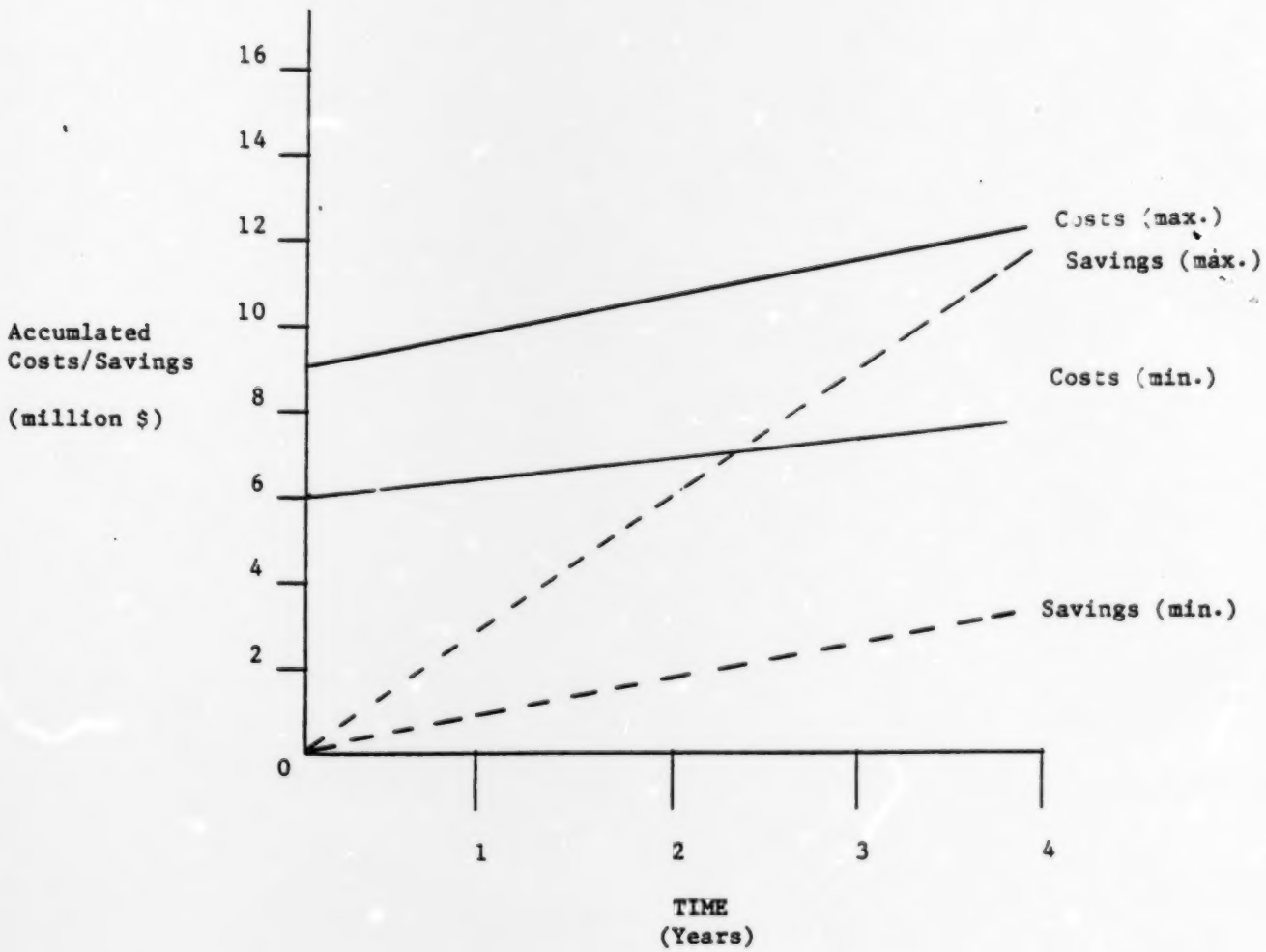
minimum:	$0.1m	to purchase new wheelchairs with interface
	$0.3m	to purchase new vehicle with interface
	$0.46m/yr	
maximum:	$0.5m	to purchase new wheelchair with interface
	$0.36m	to purchase new vehicle with interface
	$0.86m/yr	

The incremental savings to the paratransit fleet operator are calculated as:

minimum:	$0.81m/yr. due to system efficiencies.
maximum:	$3.26m/yr. due to system efficiencies.

From Figure 5 it can be seen that the worst case is the minimum annual savings (0.81m/yr.) and the maximum annual costs (0.86m/yr.). These two curves are divergent, thus ensuring that no economic payback period exists. However, the best case scenario is that of minimum costs and maximum savings, which results in a economic payback period of between two and three years.

FIGURE 5
IMPLEMENTATION PAYBACK PERIOD
FOR PARATRANSIT FLEETS OPERATING AT CAPACITY



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(1) "Development of a Wheelchair Securement System, Interim Report I" (TES Limited, Ottawa, February, 1987), p. 2.

(2) T.E. Geehan, R.R. Geenan, and T.N. Smith, Transportation and Disabled Persons: A Canadian Profile, TP 8862E (1988), p. 12.

(3) Ibid., p. 10.

(4) Ibid., p. 14.

(5) "Development of a Wheelchair Securement System, Interim Report 2", TES Report C839-2 (TES Limited, Ottawa, 1987), Appendix 4.

(6) Transit Services for the Disabled in Canada: 1986 Data (Canadian Urban Transit Association, Toronto), p. 11.

(7) "Development of a Wheelchair Securement System, Interim Report 2," TES Report C839-2 (TES Limited, Ottawa, 1987), Appendix 4.

(8) Transit Services for the Disabled in Canada: 1986 Data (Canadian Urban Transit Association, Toronto), p. 7.

(9) Ibid., p. 11.

(10) Ibid., p. 14.

(11) Based on 12 percent of operating costs.

(12) Based on 1986 ridership level of 3,551,480 persons.